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# Development of a High Flow Oxygen Analyzer for Monitoring Oxygen Therapy in Adults Using High Flow Nasal Cannula (HFNC)

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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 uses an Arduino microcontroller to process the oxygen concentration output from the OOA101-1 oxygen concentration sensor, then the processed oxygen concentration will be displayed on the TFT LCD. The variable in this study is the oxygen concentration setting value, while the independent variable is the OOA101-1 oxygen concentration sensor. The concentration value was adjusted using an oxygen blender, while the comparison tool used was gas flow analysis (Citrex H3). In the testing phase, the measurement value is 50% to 100% with a time of 1 minute at each point. Based on the measurements that have been made, the largest error value is obtained at a concentration of 50%, which is 3.07% and the smallest error value is at 100%, which is 0.40%. 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. From these results, the calibrator module has an error (value) which is still within the relative limits of the conclusion, which is ±5%. And also the design of this tool is portable and low cost and made for use in hospital companies as maintenance of HFNC equipment.

**INDEX TERMS** HFNC, Calibration, OOA101-1, Oxygen Concentration, Gas Flow Analyzer

## I. INTRODUCTION

Inaccuracy in the dosing of HFNC can cause effects on the patient. Side effects of using HFNC include gastric insufflation (air entry into the stomach) because HFNC increases a 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 air leaks have not been reported in the use of HFNC for adults, similar events may also occur in adults, so close monitoring is needed, especially on oxygen flow. 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 mmH2O/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 cmH2O[5], as observed when healthy volunteers breathe with their mouths closed with the use of HFNC. Airway pressure will increase by about 3 cmH2O at 30 $m^3/s$ oxygen and by about 12 cmH2O at 100 $m^3/s$ [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 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)[8][9][10]. 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%[4][13] 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), 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[14][15] must be monitored because if this tool is unstable and inaccurate it can cause serious problems for patients. 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[16], 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[17], in this study the sensor used was the AWM5000 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 [18]. 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[19]. 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[20]. 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[21]. This tool uses the SFM4100 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 (Oxygen Concentration Monitoring Analysis)" which is used to help facilitate medical personnel or equipment operators in monitoring oxygen concentrations. that enters the patient's body so that oxygen therapy can be given according to the right dose. Here we will analyze the oxygen concentration value that comes out of the HFNC device with the oxygen concentration 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 monitor the flow value and oxygen concentration on the HFNC.

## II. METHODHOLOGY

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 an Arduino microcontroller to process the oxygen concentration output from the OOA101-1 oxygen concentration sensor, then the processed oxygen concentration will be displayed on the TFT LCD[12][16]. The variable in this study is the oxygen concentration setting value, while the independent variable is the OOA101-1 oxygen concentration sensor. The concentration value is set using an oxygen blender, while the comparison tool used is a 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 equation (1). The average is the number obtained by dividing the number of values by the number of data in the set.:

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

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 equation (2):

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

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 equation (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 equation (4).

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

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.**

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

The digital part consists of the arduino[22] microcontroller which is the main board of the device and the OOA101-1 oxygen concentration sensor. The overall circuit in this study can be seen in **FIGURE 2.**

**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 oxygen concentration 50%, 60%, 70%, 80%, 90%, and 100% are used and the flow setting is 30 LPM.

Eror is the difference of the actual value compared to the measured value of the High Flow Oxygen Analyzer module. It can be seen in the table below that the biggest error value from the measurement of the High Flow Oxygen Analyzer module is at the 50% oxygen concentration setting with an error value of 3.07%. While the largest error value is at 100% setting with an error value of 0.40%. This explanation can be referred to in **TABLE 1.**

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

| Setting Concentration | Error |
|---|---|
| 50% | 3.07% |
| 60% | 1.95% |
| 70% | 1.62% |
| 80% | 2.56% |
| 90% | 1.32% |
| 100% | 0.40% |

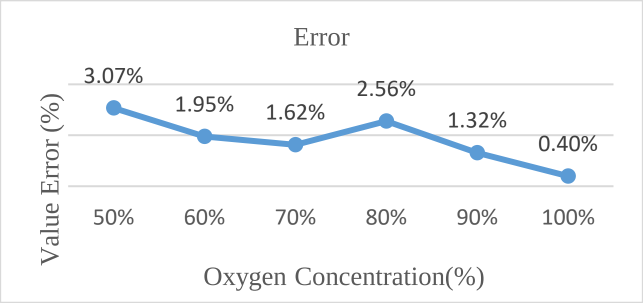


FIGURE 3. Graph of the error value for each setting in the comparison of the value of the High Flow Oxygen Analyzer module with the Citrex H3 comparison tool

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 3.07% at the oxygen concentration setting at 50%. 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.

When viewed from the error value of each oxygen concentration setting every minute, the longer the data collection time, the more stable the oxygen concentration 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 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.

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

| *Setting* oxygen concentration | Standard Deviation | |
|---|---|---|
| | Calibrator | Device |
| 50% | 0.04 | 0.3 |
| 60% | 0.07 | 1.18 |
| 70% | 0.05 | 0.46 |
| 80% | 0.09 | 0.2 |
| 90% | 0.16 | 0.56 |
| 100% | 0.41 | 0.91 |

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 High Flow Oxygen analyzer module measurements. 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 oxygen concentration setting on the module and comparison tools

| *Setting* oxygen concentration | Uncertainty | |
|---|---|---|
| | Calibrator | Device |
| 50% | 0.02 | 0.13 |
| 60% | 0.03 | 0.53 |
| 70% | 0.02 | 0.21 |
| 80% | 0.04 | 0.09 |
| 90% | 0.07 | 0.25 |
| 100% | 0.18 | 0.41 |

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 60% oxygen concentration setting which had the same value of 0.53, while the smallest deviation value was at 80% oxygen concentration setting with a small value of 0.09%.

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

| *Setting* oxygen concentration | Correction | |
|---|---|---|
| | Calibrator | Device |
| 50% | 3.1 | 4.5 |
| 60% | 3.5 | 4.6 |
| 70% | 5.9 | 6.9 |
| 80% | 6.6 | 8.4 |
| 90% | 6.4 | 8.0 |
| 100% | 6.5 | 6.6 |

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 oxygen concentration setting at 80%, namely 8.4 on the module and 6.6 on the calibrator. For the smallest correction value at 50% oxygen concentration setting, that is 4.5 on the module and 3.1 on the calibrator

If on average, the correction value of the calibrator at each oxygen concentration setting is 5.32, while the average correction value for the module is 6.49. 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 greater than that of the gas flow analyzer calibrator.It can be said that the height of the correction tool when setting the oxygen concentration is influenced by the use of a humidifier. According to research conducted by Chranjit Kaur[2] adding a humidifer to the circuit has the effect of reducing the oxygen concentration by 1 to 5%. In the research that has been done, the researchers here use the OOA101-1 oxygen concentration sensor on the high flow oxygen analyzer module that has been made. The addition of a humidifier in the intake of the high flow oxygen analyzer module reduces the oxygen concentration value by 1 to 9.5%.

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.

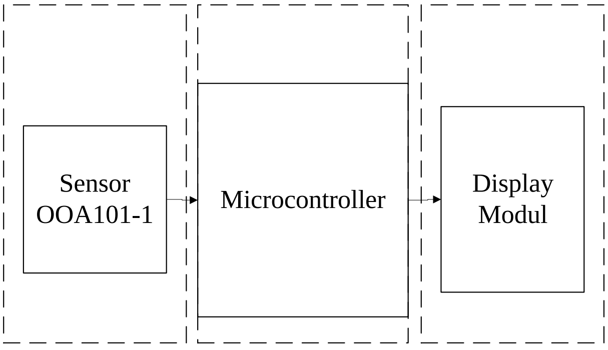


FIGURE 4. The diagram block of the system in research design of high flow oxygen analyzer using OOA101-1 sensor

This paragraph can explain FIGURE 4 the block diagram above has 3 main parts, namely process input and output, the input consists of the OOA101-1 oxygen concentration sensor which is the source of data input 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.

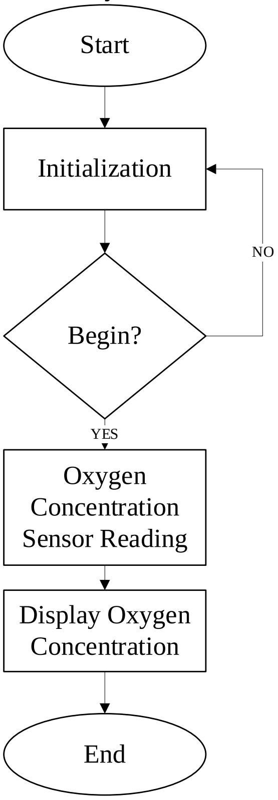


FIGURE 5. Flowchart system in research design of high flow oxygen analyzer using OOA101-1 sensor

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 oxygen concentration and continues to display the value read by the sensor.

## IV. DISCUSSION

After testing the High Flow Oxygen analyzer[23][24] module, data collection and analysis were carried out to determine the accuracy of the value of the OOA101-1 sensirion sensor output as a flow sensor used to monitor the oxygen concentration value on the HFNC (High Flow Nasal Canulla) device. After conducting experiments on research to obtain oxygen concentration 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 oxygen concentration settings, 50, 60, 70, 80, 90, and 100%, the results of the oxygen concentration values are stable. The oxygen concentration setting value which has the lowest error value of 0.40% is found in the 100% oxygen concentration setting and the highest error value is at the 50% oxygen concentration setting at 3.07%. The best data distribution is the oxygen concentration setting at 80% with a standard deviation value of 0.2 which produces an uncertainty of 0.09. The value of uncertainty if it is close to 0 can be interpreted if the stability of the results is very good because it does not have a change in each measurement. While the correction value for oxygen concentration can be said to be quite high due to a large difference when setting the oxygen concentration at 80%, which is 8.4.

The magnitude of the correction of the oxygen concentration value is due to the addition of a humidifier on the HFNC device. In previous research, adding a humidifier to the oxygen concentration circuit can reduce the oxygen concentration value by 1-5%[4]. This is a reference if the concentration value obtained in this study using the OOA101-1 oxygen concentration[25][26] sensor has a relatively high correction value that can still be tolerated. And also for the oxygen concentration parameter, it takes a longer time than the flow parameter on this high flow oxygen analyzer module to achieve a stable value and close to the value of the HFNC calibrator. It takes up to more or less more than 5 minutes so that the results obtained are stable well.

First the output on the oxygen concentration sensor still has to be adjusted and converted again to percent (%) so that the results of the oxygen concentration can be the same as the manufacturer's gas flow analyzer calibrator. Henceforth, the authors suggest using another oxygen concentration sensor so that the correction results obtained are not too large. must then readjust the oxygen concentration conversion value to better fit the required scale, and the last is that the oxygen concentration results obtained have a fairly large error value and correction value when added to the use of a humidifier, due to the partial pressure of saturation pressure generated when using a humidifier[27][9].

## IV. CONCLUSION

The purpose of this study is to test and prove the results of setting the oxygen concentration parameter on the High Flow Oxygen analyzer by comparing it with the HFNC calibrator, namely the gas flow analyzer, it can be concluded that from the research method, data collection, and analysis of the results of measuring oxygen concentration parameters using gas flow analyzer CITREX H3 is a measurement of oxygen concentration monitoring parameters on the High Flow Oxygen analyzer module that can be known through the OOA101-1 oxygen concentration sensor using an HFNC gas flow analyzer calibrator. In the measurement of the oxygen concentration parameter setting which has the lowest error value of 0.40%, it is found in the 100% oxygen concentration setting and the highest error value is in the 50% oxygen concentration setting of 3.07%. The standard deviation of the 80% oxygen concentration setting has the smallest value of 0.2 and the smallest uncertainty value (UA) of 0.09. And the biggest correction value is ±6.6 on the HFNC calibrator and ±8.4 on the High Flow Oxygen analyzer module, namely the 80% oxygen concentration setting. then the magnitude of the correction value and the error value on the oxygen concentration is due to the addition of a humidifier on the HFNC device. The use of a humidifier on HFNC devices can reduce the oxygen concentration value by 1-5% according to previous research. And also the length of time for taking oxygen concentration data so that the value obtained is more stable and closer to the value of the HFNC calibrator. Furthermore, after 5 minutes of reading the oxygen concentration that has been done, it can be seen that the longer the data collection is carried out, the more stable the oxygen concentration value from the module and calibrator.

For developments that can be done in the future is to use another oxygen concentration 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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