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Design of Carbon Dioxide Levels Measurement in Human Expiration Using End Tidal Carbon Dioxide (EtCO2) Capnography Method

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ABSTRACT Asthma is a chronic respiratory disease that has become the main reason patients are always rushed to the hospital emergency department. Capnography is a new method for examining asthma by measuring CO2 levels released by the lungs. The aim of this research was to create an EtCO2 capnography device that is able to measure CO2 levels in patients with asthma or difficult breathing to assist doctors in determining the urgency of using a ventilator in a patient. The EtCO2 Capnography device used in the hospital uses a sensor that is expensive, but in this study, a CO2 gas sensor type Cozir-WX-20 was used at a low price. The research was conducted by utilizing a CO2 gas sensor type Cozir-WX-20 which read CO2 concentration in ppm value and a microcontroller as an analog to digital data processor to be displayed on the LCD. Sensor characterization was carried out to compare the side-stream and main-stream methods, response time readings, and the accuracy of the cozir sensor. The resulting data were taken from CO2 cylinders and medical air gas at various flow volume values and was connected to the Cozir sensor, EtCO2 main-stream patient monitors, and side-stream EtCO2 patient monitors. The resulting CO2 readings from CO2 tubes and medical water on the Cozir-WX-20 sensor and main-stream patient monitors obtained an error of 4.6%, namely at a CO2 concentration of 7% or 70,000 ppm and sensor accuracy is above 95%. As for the side-stream method, the reading error is 1.96% and 1.74% at a CO2 concentration of 6-7%. Sensor accuracy on the side-stream method cozir module is above 95%. Response time reading CO2 gas at a concentration of 1%-7% under 5 seconds. It is hoped that this inexpensive EtCO2 Capnography device can be used for diagnostic purposes in the emergency room or intensive care unit to quickly and accurately determine the urgency of using a ventilator in a patient to avoid a fatal condition.

INDEX TERMS, Carbon dioxide, Sensor Cozir-WX-20, Main-stream, Side-stream, EtCO2 Capnography

I. INTRODUCTION

Asthma is a chronic respiratory disease and has become the main reason patients are always rushed to the hospital emergency department [1]. The method currently used to monitor asthma conditions is to use a tool called a peak flow meter [2][3]. Peak flowmetry and spirometry have limitations, where they require a strong blowing force from the patient to get a diagnosis of asthma [4]. In a recent study, capnography is a new method for monitoring asthma conditions using infrared technology which measures the level of expiratory CO2 and helps doctors understand the respiratory status of patients with asthma [3]. Capnography is a graphic technique that expresses the level of CO2 expiration at a time and produces the results of measuring EtCO2. In this case, the measuring instrument is called a capnometer and the graph wave that is displayed is a capnogram. CO2 is absorbed by infrared light which has a wavelength of 4.26 um. The amount of light that is absorbed is proportional to the concentration of the absorbed molecules. The concentration of CO2 on expiration passes through the infrared and is compared to the amount of energy that does not contain CO2 [5]. The technical guidelines of the American Association of Sleep Technologists explain that the normal CO2 condition is 35-43 mmHg or 5-6% [6][7]. M. Khezri's research in 2015 stated that for patients with mild asthma, the level of CO2 expiration will drop below 35 mmHg, and for patients with severe asthma will be more than 60 mmHg [8]. Therefore, Nasal capnography can be used for monitoring non-intubated respiratory patients in the emergency department [9]. Several problems have been mentioned in previous research projects, namely in 2010 Research on the detection of expiratory CO2 levels, which was studied by Lita Safitrin. This study used a TGS4160 sensor and is linear but has a weakness in the design of the tool, where it was not calibrated with the EtCO2 calibration tool. The measurement results are still in PPM units with a measurement range of 32,000-44,000 ppm [10]. In 2017, research was done on CO2 with a portable design for asthma screening by Sameen Ahmed Malik, Om Prakash Singh, Aimi Nurifhan This research has advantages in designing the EtCO2 sensor module which is cheap for the community and supports early detection of asthma diagnosis. However, the weakness is that researchers used GLCD where the graphic image was still not clear and the wave or graph used was still a sinusoid which is difficult to understand for inspiration and expiration detection [1].

In 2018 Hamed Aminiahidashti, Sajad Sahfiee, Alieh Zamani Kiasari conducted a study on the application of EtCO2 in the emergency department. This study has advantages in explaining diseases that must be detected using EtCO2 in emergency cases so that the use of EtCO2 can be maximized in early diagnosis in the Emergency Unit at a Hospital. The weakness is that researchers still need further research to evaluate applications in specific clinical and disease-specific applications and there was no module development yet [11]. In 2017, Cheow Shek Hong conducted research on the development of an electronic device to detect asthma. It has the advantage of low-cost sensors in the design and manufacture of capnography modules so that they can be used for early detection in the surrounding community. The researcher used the MH-Z14A sensor and the asthma and normal indicators were indicated by the presence of a red LED and displayed on the LCD and Bluetooth as a data sender to the PC in graphic form. However , this study has a weakness in the use of incomplete measurement data, namely 5000 ppm and graphic form that needs to be validated [4]. In 2003, Kabita shakya, Chaterin deegan, Fran conducted a study entitled determining the frequency response of EtCO2 analyzer where the level EtCO2 is expressed in percentage or mmhg. This research has the advantage of comparing the frequency response of a sensor from Draeger capnologist. In addition, this study also has a weakness, in which Capnography research was only done on the side-stream method [5]. In 2017, Francisco Jose and Jesus Molina-Mula conducted a study on capnography as a means of detecting metabolic changes in patients in the emergency department. This study revealed the correlation between bicarbonate acid and EtCO2 to diagnose metabolic acidosis at an EtCO2 value less than 24.5 mmHg. Its drawbacks require further clinical evaluation [12]. In 2015, Ahmad O. Muhtaseb, Firas M, J. Al-Haddad conducted a study on the implementation of a diabetic ketoacidosis detector. The advantage is that the design of the patient's CO2, respiration rate, heart rate will be used to diagnose diabetic ketoacidosis with display values, alarms and sound output for patient instructions if the value of EtCO2 is less than 24.5 mmHg. The detection used the MG811 10000 PPM sensor so that to measure the level of 24.5 mmHg it can be read. The weakness is that when the nasal mask and sensor were not used on the patient, the sensor still reads the level of CO2 in the room and the buzzer sounds and requires clinical evaluation in this initial diagnosis [13]. In 2018, Om Prakash and MB Malarvili conducted a study by reviewing several infrared sensors for CO2 detection and capnograms for asthma detection tools. The advantage of this research is that data from various brands of CO2 sensor data was taken to show accuracy and sensitivity in end tidal CO2 readings to develop asthma monitoring tools. Meanwhile, its weakness is that some of the CO2 sensors have readings in ppm units, while what is needed is low cost and has mmhg units to make it easier for operators to diagnose [14]. In 2020, Tatsunori Jo, Minoru Inomata, Kohei takada etc. conducted a study entitled Usefulness of measurement of End Tidal CO2 using a portable capnometer in patients with chronic respiratory failure receiving long term oxygen therapy. The method used is a quantitative method. The advantage of the study is that researchers were looking for the relationship between EtCO2 and PVCO2 using EtCO2 capnoeye brand, data due to oxygen therapy were also proven by an increase in EtCO2. The weakness is that the clinical data was incomplete [15]. In 1994, B. You. R. Peslin, C. Duvivier conducted a research entitled Expiratory Capnography in Asthma: evaluation of various shape indices. This study applied quantitative methods. The advantages of the research are the variations in data collection and measurement [16]. In 2013, Daniel Santoso and Fransiscus Dalu Setiaji conducted research entitled Design and Implementation of capnograph for laparoscopic surgery through quantitative methods. The advantage of the method applied is that the EtCO2 prototype using the integrated analyzer module showed accurate results compared to the manufacturer's EtCO2 tool. The downside is that the sensor is expensive and has to be imported [17]. In the 2015, patent conducted by Ammar Al-ali with the title Assistive capnography device. With quantitative methods. The advantage is that the tools and applications are very simple and utilize a bag valve mask as a breathing aid, plus monitoring the values of EtCO2 and RR so that this tool can be used in ambulances and emergency units. The weakness of this tool is that it relies on batteries which must be considered since this tool is used in emergency patients [18]. Main-stream vs. side-stream capnometry for prediction of arterial carbon dioxide tension during supine craniotomy was then done in 2003 by K.L. Chan, to compare the PaCo2 measurement method using the main-stream and side-stream methods. The advantage of this study is that the main-stream method was used for measurements in neurosurgery patients and showed better results than side-stream because the side-stream method still had CO2 gas leakage so that the measurement had an effect [19]. In 2017, Tjokorda Gde Agung Setiaji conducted a study entitled The End Tidal CO2 correlation with decreased cardiac output measured by ultrasonic cardiac output monitor in intubated ICU patients. The method used is observation. The advantages are that data collection and measurement are accurate and there is a correlation between EtCO2 and cardiac output. The disadvantage is that the study is expected to be conducted in an emergency department with patients in shock [20]. In 2009, a study entitled Effort independent portable, user operated capnograph devices and related methods was conducted by J. Goepp. The advantage of this research is that the researchers made a portable EtCO2 detection tool and there is memory access to store the baseline CO2 measurement. The weakness is that there is no alarm system and patient disease detection [21]. In 2019, Monisha Srabanti conducted research entitled the Design of NDIR based CO2 sensor to detect human respiratory CO2. The advantage is the use of a cheap sensor, while the weakness is that researchers expect data collection in the OK room, namely during anesthesia and the NDIR sensor used is still in the range of 35,000-50,000 PPM which is less accurate when used to measure CO2 levels in expiration, namely 35-43 mmHg at normal patient. In addition, it used main-stream method because it is more accurate than the side-stream. The side-stream method is not recommended for intubated patients and transmission on the tube also makes the measurement delay too long [22]. In 2015, C Pantazopoulos conducted research entitled A Review of Carbon Dioxide Monitoring During Adult Cardiopulmonary Resuscitation through a quantitative method. The advantage is that the researcher aimed to measure the effectiveness of expiratory CO2 levels during CPR or cardiopulmonary resuscitation. The weakness is that the researcher explained the implementation and correct interpretation when the CPR value changed and the minimum EtCO2 20 mmhg [23]. In 2012, M Kazemi and M. Malarvi conducted a study entitled Analysis of capnogram using linear predictive coding (LPC) to differentiate asthmatic conditions. The method used is a quantitative method. The advantage of this research is that the EtCO2 examination can detect asthma during an emergency. The weakness is that the EtCO2 asthma monitoring tool needs to be made [24]. In 2013, research was conducted on the Association between Capnogram and Respiratory Flow Rate Waveforms during Invasive Mechanical Ventilation. It examined the relationship between capnogram and respiratory flow rate. The method used is qualitative, comparing the respiration flow rate and CO2 phase 0 - phase 3. The disadvantage is that in the rebreathing wave there was an additional expiratory alveolar plateau wave [25]. Based on the literature, a "Design of EtCO2 Level Measurement in Human Expiration was made using the EtCO2 Capnography Method [10][5][22][10].

Related to the previous projects, current research was carried out aiming to develop an EtCO2 Capnography module that can measure CO2 levels at an affordable price for asthma patients that can be used for early detection at home [9] and also for emergency CPR patients [23]. This research produced a portable EtCO2 capnography device to measure CO2 levels from the lungs as early detection of asthma or early detection of lung conditions that can be done independently at home. Checking lung conditions independently is to prevent fatal conditions because medical treatment can be done immediately when measured CO2 levels are not normal. This portable EtCO2 capnography device used a CO2 gas sensor type Cozir-WX-20 at a low price and was made portable so that it can be used independently at home.

This article consists of Chapter 1 Introduction which contains background, references, and research objectives, Chapter 2 Materials and Methods explaining the stages and processes of data collection, tools and materials, block diagrams, and research flowcharts, Chapter 3 Results are presented with tables and figures the image showing the performance of the EtCO2 Capnography tool, the results of which will be discussed in detail in Chapter 4 Discussion. Chapter 5 Conclusion presents this study's main findings and future work.

II. MATERIALS AND METHODS

A. EXPERIMENTAL SETUP

In this study, there are 2 types of EtCO2 Capnography measurements, namely main-stream, and side-stream. The main-stream type was used when the patient can breathe normally so that the sensor was placed directly on the nasal cannula, while the side-stream type was intended for patients who need ventilator assistance to breathe so that a pump is needed so that CO2 blows to reach the sensor. The research data collection method for testing the EtCO2 Capnography system is simulated by flowing CO2 gas and medical gas on the Cozir-WX-20 sensor. The flow rate of CO2 gas and medical gas is regulated using a flowmeter with various values. The CO2 level value from the flowmeter setting shown from the Cozir-WX-20 sensor reading will be compared with the CO2 value shown on the calibrated patient monitor.

1) MATERIALS AND TOOLS

The manufacture of the EtCO2 Capnography module and the stages of testing a system capable of measuring CO2 levels require several materials. These materials included ultra low CO2 sensor Cozir-WX-20%, microcontroller ATMega 328, LCD 16x2, CO2 gas and medical gas cylinders, regulator/flowmeter for CO2 gas and medical gas, breathing circuit and Y-piece, nasal cannula tube, patient monitor of General Electric Type B125, and Dash 4000.

2) EXPERIMENT

Each nasal tube was connected to each flowmeter to a CO2 gas cylinder and a medical gas cylinder, which in turn connected the two nasal tubes to the Y-piece breathing circuit. The Cozir-WX-20 sensor hose was then connected into the Y-piece breathing circuit and into the patient monitor device. Furthermore, the EtCO2 was measured by opening and closing the CO2 and medical gas flowmeter knobs for a 2-second pause to produce a respiration rate that makes it easier for patient monitors to detect CO2 levels. The CO2 level from the EtCO2 Capnography module was then compared to the value shown on the patient monitor.

B. THE DIAGRAM BLOCK

FIGURE 1 shows the CO2 concentration reading command that was carried out by the TX RX sensor with a microcontroller with serial communication facilities. This study used 2 types of EtCO2 Capnography, namely main-stream and side-stream. In the main-stream type, the ATMega 328 microcontroller which functions as a data processor receives the data in the form of CO2 levels from the Cozir-WX-20 sensor which was connected to the UART TX RX connection to be displayed on the LCD. In the side-stream type, a 5 Volt DC pump was required to flow CO2 gas to the Cozir-WX-20 sensor.

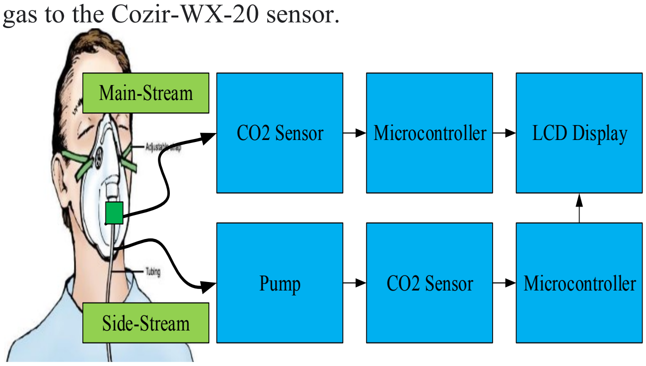

FIGURE 1. Block diagram of main-stream and side-stream capnography devices

C. THE FLOWCHART

FIGURE 2 shows a flowchart of applying the resulting model to side-stream and main-stream EtCO2 capnography. In the main-stream type, the patient's breath on the patient's nasal cannula or CO2 gas with flowmeter settings passes through the Cozir-WX-20 sensor which read the CO2 level to be displayed on the LCD. The side-stream type requires a motor to pump CO2 gas from the patient or a flowmeter to the Cozir-WX-20 sensor because this type was used for patients who need a ventilator as a breathing aid.

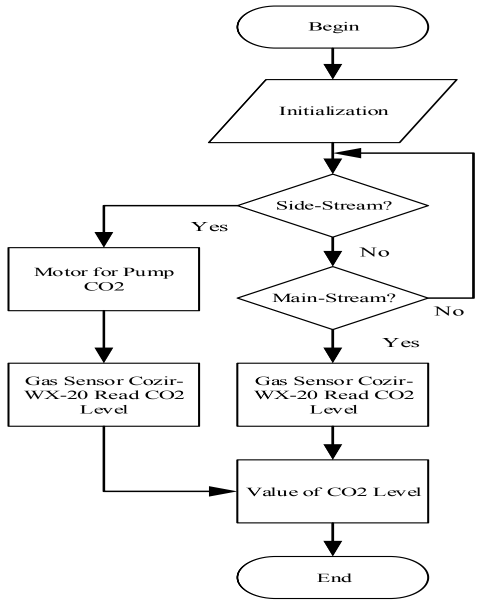

FIGURE 2. The flowchart for reading CO2 level data on main-stream and side-stream types

III. RESULT

In this study, test has been done to determine the accuracy of the results.

A. DESIGN MODULE BUILD

FIGURE 3 is the results of the design of the EtCO2 Capnography tool with 2 types of CO2 measurement, namely main-stream and side-stream are shown in Fig.3. The Arduino Uno microcontroller was connected to a pump that circulated CO2 gas to the Cozir-WX-20 sensor to read CO2 levels with a side-stream type. In the main-stream type, the microcontroller instructed the Cozir-WX-20 sensor to directly read CO2 levels. The Cozir-WX-20 sensor was connected to the UART microcontroller, namely TX RX. FIGURE 4 shows the documentation for testing and preparing CO2 gas cylinders, medical gas and CO2 tube, flowmeters, breathing sets, nasal tube measurement modules using patient monitors, and the Cozir-WX-20 module in the intensive care unit room.

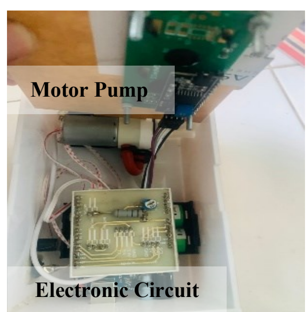

FIGURE 3. Module Design

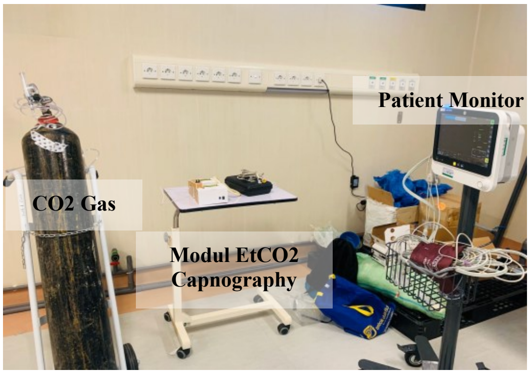

FIGURE 4. Testing CO2 Tube

B. RESULTS DATA

In this sub-chapter, the results of the research is presented, showing the performance of the EtCO2 Capnography device compared to calibrated devices, namely patient monitoring as the gold standard. Some of the results of this study were in the form of a comparison of the readings of CO2 between Monitor Patients and EtCO2 Capnography types of main-stream and side-stream. Comparison was done between the accuracy of CO2 readings for Patient Monitor and EtCO2 Capnography for main-stream and side-stream types and between the response time for Cozir-WX-20 sensor readings for main-stream and side-stream types.

FIGURE 5 presents a comparison graph of the CO2 level reading values of the main-stream type with patient monitoring devices. The graph in Fig.6 shows a comparison of the side-stream type and the monitor patient. CO2 levels displayed in units of parts per million (PPM) are set from 1000 – 7000 ppm.

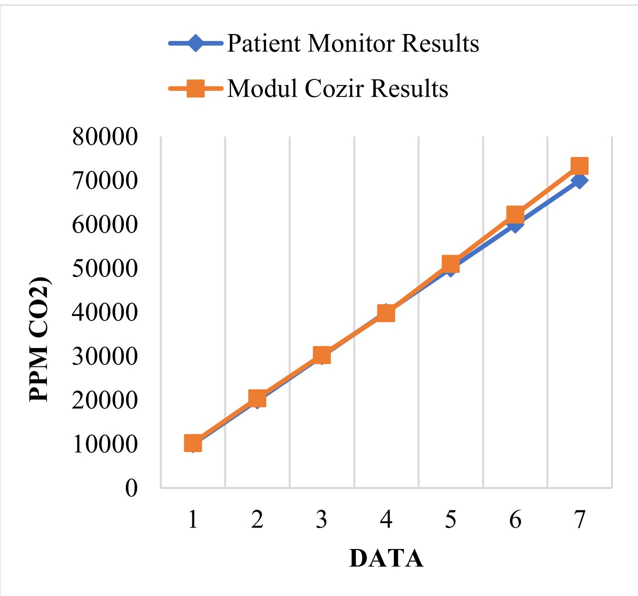

FIGURE 5. Comparison Module and Patient Monitor Results.

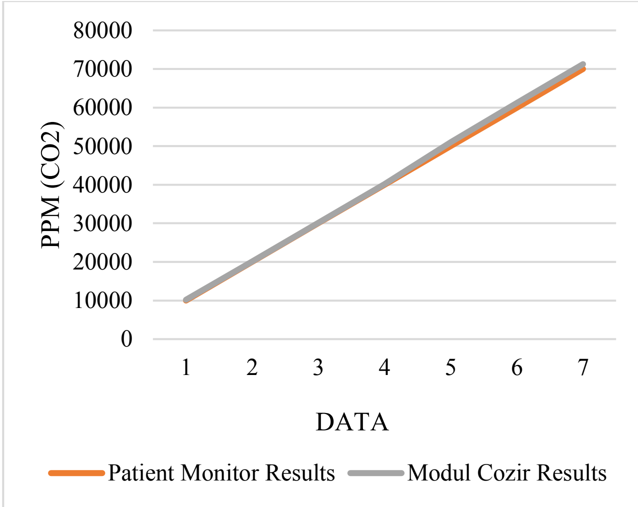

FIGURE 6. Cozir Module Test, Patient Monitor and Gas Cylinder.

The accuracy value for reading the Cozir-WX-20 sensor CO2 level value in the forms of percentage (%) between the main-stream and side-stream types is shown in Table I. The CO2 level measured ranges from 1% to 7%, regulated via a CO2 gas flowmeter and gas medical. Table II presents the results of a comparison of the response time of the Cozir-WX-20 sensor readings between the main-stream and side-stream types. The table shows that the Cozir-WX-20 sensor on the main-stream type takes longer to read CO2 levels than the side-stream type. This is because the side-stream type uses a motor to pump CO2 flow to the Cozir-WX-20 sensor so that sensor readings become faster.

TABLE 1
Main-stream and Side-stream Accuracy

Co2 Rate (%)	Accuracy (Main-stream)	Accuracy (Side-stream)
1%	97.7%	97.87%
2%	98.6%	99.35%
3%	98.4%	99.6%
4%	98.8%	99.6%
5%	97.3%	98.54%
6%	96.3%	98%
7%	95.4%	98%

TABLE 2
Main-stream and Side-stream Method Response Time

Co2 Rate	Main-stream Time (s)	Side-stream Time (s)
1%	1	1.5
3%	3	2
5%	4	3
7%	5	4

Table III shows the results of reading CO2 levels in medical gas-mixed CO2 gas cylinders. The results revealed that the patient monitor was calibrated from 1% to 7% levels, and the main-stream cozir module read at levels of 10.230 ppm to 73.300 ppm, with the lowest accuracy of 95.4 percent at 7% CO2 gas concentration. The side-stream approach readings at levels of 10.200-7.250 ppm, with the lowest accuracy of 97 percent and the greatest error of 2.3 percent at 1% Co2 gas concentration, which is still within the error range for the cozir wx sensor specification of 5%.

TABLE 3
Comparison Cozir Module and Patient Monitor

Patient Monitor Measurement	Module Cozir Measurement (main-stream)	Module Cozir Measurement (side-stream)
1% (10.000)	10.230 ppm	10.200 ppm
2% (20.000)	20.450 ppm	20.100 ppm
3% (30.000)	30.240 ppm	30.100 ppm
4% (40.000)	39.800 ppm	40.140 ppm
5% (50.000)	51.000 ppm	51.000 ppm
6% (60.000)	62.240 ppm	61.240 ppm
7% (70.000)	73.300 ppm	71.250 ppm

IV. DISCUSSION

The results of reading CO2 levels in medical water-mixed CO2 gas cylinders has been presented. The results revealed that the patient monitor was calibrated from 1% to 7% levels, and the main-stream cozir module read at levels of 10.230 ppm to 73.300 ppm, with the lowest accuracy of 95.4 percent at 7% CO2 gas concentration. The side-stream approach readings at levels of 10.200-7.250 ppm, with the lowest accuracy of 97 percent and the greatest error of 2.3 percent at 1% Co2 gas concentration, which is still within the error range for the cozir wx sensor specification of 5%. The outcomes of a side-by-side comparison of response times for reading CO2 levels on the Cozir wx sensor using the main-stream and side-by-side methods. The main-stream method took longer to read Co2 levels on the cozir wx sensor than the side-stream method. Because the side-stream method includes a dc pump motor, it aids in the measurement of CO2 levels.

The outcomes of this study were superior to the previous investigations. Clinical investigations that aid in the diagnosis of asthma patients more quickly have increased acid (kidney) indications, diabetic ketoacidosis by looking at C)2 levels in patients, which was not identified in the study [11][12][13].

The results of reading CO2 levels on the EtCO2 device for the main-stream and side-stream types still have a difference with the patient monitor device as the gold standard. Data collection activities must also alternate with the use of patient monitoring devices for patient care. In addition, the conversion of CO2 levels from ppm to percent (%) has not been integrated into the system but is still done manually.

The EtCO2 data produced from CO2 level sensor readings can be valuable for the community in early detection of lung problems thanks to this module. By looking at the patient's Co2 level, the equipment can be utilized in the emergency room for patient evaluation and helps diagnose asthma, acid indications (increased renal function), and diabetic ketoacidosis faster.

V. CONCLUSION

The goal of this study is to use the Capnography method to build a design for EtCO2 levels in expiratory lungs. The resulting CO2 readings from CO2 tubes and medical water on the cozir wx sensor and main-stream patient monitors get an error of 4.6%, namely at a Co2 concentration of 7% or 70,000 ppm and sensor accuracy is above 95%. As for the side-stream method, the reading error is 1.96% and 1.74% at a Co2 concentration of 6-7%. Sensor accuracy on the side-stream method cozir module is above 95%. Response time reading Co2 gas at a concentration of 1%-7% under 5 seconds. In this study, the Cozir Wx-20% Co2 Sensor has a good accuracy from the range of 1%-7% for testing the expiratory level of Etco2. Future research should try to use this type of infrared sensor and display CO2 levels using IoT so that patients who are at home can easily be monitored by doctors.

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