Jurnal Teknokes
Homepage: teknokes.org; Vol. 18, No. 1, pp. 50-58, March 2025;

e-ISSN: 2407-8964
p-ISSN: 1907-7904

RESEARCH PAPER

OPEN ACCES

Analysis of Inspiratory Minute Volume (mVi) and Expiratory Minute Volume (mVe) Parameter Measurement using Flow Analyzer Design with Volume Control Ventilation (VCV) Mode on Ventilator

Levana Forra Wakidi [1], Farid Amrinsani [1], Alfi Nur Zeha[1], **and** Riqqah Dewiningrum [1]

[1] **Department of Medical Electronics Technology, Poltekkes Kemenkes Surabaya, Surabaya, Indonesia**

ABSTRACT

Flow analyzers are used to measure, monitor, and calibrate air or gas flow parameters in medical devices, especially ventilators. In VCV mode, the ventilator sets a fixed inspiratory volume for each breath of the patient. This study aims to develop a flow analyzer with Inspiratory Minute Volume (mVi) and Expiratory Minute Volume (mVe) parameters with Volume Control Ventilation (VCV) mode to precisely measure the volume of air inhaled and exhaled by the patient, so as to validate the performance of the ventilator according to clinical standards. Data collection was performed using the VCV mode and 6 trials were conducted at each setting. The ventilator was set with tidal volumes of 200ml, 300ml, 400ml, 500ml, and 600ml and with an I:E ratio of 1:2 and a PEEP pressure of 5cmH2O. Based on the available data, the Minute Volume Expiratory (MVE) parameter showed the highest error in the tidal volume setting of 300 mL with a value of -14.7%. After the module was adjusted, the 600 mL tidal volume setting had a mean error of 0.69 with a standard deviation of 1.351, while the 200 mL setting recorded the lowest mean error of -0.12. Module adjustments and manual calculations yielded more accurate information, indicating that lower tidal volume settings, such as 200 mL, can improve measurement accuracy on ventilators. Overall, this study shows that while higher volume settings can increase data variation, lower settings can provide more consistent and accurate measurement results. The use of the AFM 3000 sensor on the Flow Analyzer proved to be viable for airflow measurement on ventilators. This study is expected to create a low-cost flow analyzer capable of measuring MVi and MVe parameters, enabling medical personnel to ensure ventilators are functioning optimally, measuring airflow in and out of the lungs so as to ensure sufficient oxygen for metabolism and carbon dioxide can be discharged efficiently, supporting the care of patients with respiratory disorders, and contributing to the improvement of the quality of health services through the accuracy of ventilator measurement and calibration.

PAPER HISTORY

Received Jan 02, 2025
Revised Feb 12, 2025
Accepted March 7, 2025
Published March 30, 2025

KEYWORDS (ARIAL 10)

Short-chair;
Polyfluoroalkyl;
Spectrometry;
Ionization;
Carboxylic

CONTACT:

lep.forra@gmail.com

1. INTRODUCTION

The respiratory system is essential for life, as it allows the body to absorb oxygen from the air and remove waste gases produced from cellular reactions[1]. Ventilators play an important role in helping and monitoring the breathing of patients suffering from respiratory diseases by providing certain air pressure settings [2][3][4]. Ventilators work by regulating the flow of air in and out of the patient's lungs [5]. The need for ventilators is increasing in urgency due to the COVID-19 pandemic which disrupts the respiratory system of patients [6][7][8]. Ventilator as a form of mechanical controller of gas flow and pressure whose gradient must be made is made between the ventilator and the lungs [9][10]. Ventilators are needed for patients with acute heart failure, severe respiratory infections such as pneumonia, chronic obstructive pulmonary disease, traumatic brain injury so that they can maintain their respiratory function[11]–[13] Mechanical ventilation is essential for maintaining oxygenation, but mechanical ventilation can cause lung injury by triggering excessive stretching and improper regulation can worsen pulmonary edema[14][15].The use of ventilators to support the patient's life is required to be able to operate properly and its nominal parameters must be tested regularly [16].

Corresponding author: Levana Forra, lep.forra@gmail.com , Department of Medical Electronics Technology, Poltekkes Kemenkes Surabaya, Jl. Pucang Jajar Timur No. 10, 60282, Surabaya
DOI: https://doi.org/10.35882/teknokes.v18i1.20

e-ISSN: 2407-8964
p-ISSN: 1907-7904

Regular calibration of ventilators and anesthesia machines can reduce the risk of death as well as minimize respiratory symptoms in patients who use mechanical ventilation[17]. Calibration of the ventilator is essential to ensure the accuracy of the setting of these parameters. Calibration is performed to ensure that the ventilator delivers the right air volume, pressure, and gas mixture as per the patient's needs[18] From the flow, important parameters on ventilators can be measured, including Minute Volume Ventilation (MMV) to ensure that patients get ventilation in one minute. This Minute Volume Ventilation (MMV) parameter is applied with a different working system on each brand of equipment, for example, preset minute ventilation compared to the patient's total minute ventilation (spontaneous and mechanical) every 24 cycles, or carried out on a breath-by-breath basis. [10]. Tidal Volume (VT) and Respiratory Rate (RR) are factors that affect overall minute volume. Tidal Volume (VT) refers to the amount of air inhaled or exhaled in each respiratory cycle, while Respiratory Rate (RR) is the number of breaths per minute that needs to be adjusted during mechanical ventilation to ensure the minute volume continues to meet the metabolic needs of the patient[5].

Inspiratory Minute Volume (mVi) and Expiratory Minute Volume (mVe) are the two main parameters in mechanical ventilation used to evaluate patient ventilation efficiency. Inspiratory Minute Volume (mVi) is the volume of air inhaled by the patient in one minute. This value is obtained by multiplying (Vti) tidal volume (air volume per breath) by respiratory rate (number of breaths per minute). mVi is displayed on the ventilator device and can be adjusted to ensure the patient receives adequate air volume during the ventilation process. Expiratory Minute Volume (mVe) is the volume of air exhaled by the patient in one minute. Just like mVi, mVe is calculated by multiplying (Vte) tidal volume by respiratory rate. The MVe value is displayed on the ventilator and plays an important role in monitoring the effectiveness of ventilation, as well as setting alarms when mVe falls below a set limit. These two parameters are very important in the management of non-invasive ventilation (NIV), the ventilator automatically adjusts mVi and mVe to compensate for leaks in the system, thus ensuring that the set inspiratory pressure and PEEP are maintained[19]. mVi serves to improve oxygenation by ensuring that the volume of air inhaled per minute is sufficient to meet the body's oxygen demand. Meanwhile, mVe functions to expel carbon dioxide ($CO2$) from the body, which is important to prevent the buildup of $CO2$ that can cause blood gas problems [20].

Therefore, mVi and mVe serve as important indicators for monitoring the effectiveness of ventilation, which is also influenced by the Vti and Vte values measured during the ventilation process. Thus, monitoring of mVi and mVe, along with Vti and Vte, is critical to ensure that patients receive adequate and effective ventilatory support. mVi and mVe are key indicators of the airflow into and out of the lungs, which is critical to ensure that sufficient oxygen is available for metabolism and that carbon dioxide can be effectively removed [21]. mVi and mVe are very important parameters in healthcare, especially in mechanical ventilation for patients with respiratory distress. mVi is used to ensure that the patient receives adequate air volume during the inspiration process, while mVe serves to measure the volume of air expelled by the patient in one minute. mVe monitoring allows medical personnel to assess the effectiveness of ventilation and ensure that the patient is not hypoventilating or hyperventilating. Medical personnel can monitor mVi and mVe to adjust the ventilator settings according to the patient's individual needs. This is crucial, especially in neonatal and pediatric care, to improve outcomes while reducing the risk of complications due to inadequate ventilation [22]

In 2021, Tomy Abuzairi et al. conducted research developing an open-source and low-cost ventilator testing device developed to calibrate the output of medical ventilators, including tidal volume, inspiration pressure, and oxygen concentration. The gas flow rate sensor that the GFS131 uses to measure the tidal volume. However, this study did not feature measurements of Inspiratory Minute Volume (mVi) and Expiratory Minute Volume (mVe) parameters [23].

In 2021, Alejandro et al. designed and compared low-cost emergency mechanical ventilators during the COVID-19 pandemic in developing countries, particularly in Panama. Two types of ventilators were developed, one using the Bag-Valve (BVD) design and the other using the Intermittent Positive Pressure Ventilation (IPPV) design. MPX5010 sensors are used in both types of ventilators (BVD and IPPV) to detect the air pressure required during the ventilation process. Meanwhile, SFM3000 is used in IPPV ventilators to measure airflow with high accuracy. The test results show that both devices are working according to specifications with an error of less than 5%. However, this study did not discuss in more detail the measurement of Inspiratory Minute Volume (mVi) and Expiratory Minute Volume (mVe) parameters [24].

In 2021, Jaafar Alsalaet et al. designed an instrument used in flow measurement or flowmeter on ventilators with a design using 3D printing. The flow meter designed is a laminar flowmeter and uses a MPXV7002 sensor to measure pressure. The study used the Arduino Uno to digitize the signal received from the pressure sensor and transmit the data in real time via USB. However, in this study there is no discussion on the measurement of Inspiratory Minute Volume (mVi) and Expiratory Minute Volume (mVe) parameters [25].

Based on the problem identification and shortcomings of previous research, there are still few studies that discuss

Corresponding author: Levana Forra, lep.forra@gmail.com , Department of Medical Electronics Technology, Poltekkes Kemenkes Surabaya, Jl. Pucang Jajar Timur No. 10, 60282, Surabaya
DOI: https://doi.org/10.35882/teknokes.v18i1.20

e-ISSN: 2407-8964
p-ISSN: 1907-7904

flow analyzers with Inspiratory Minute Volume (mVi) and Expiratory Minute Volume (mVe) parameters as the main components in the measurement. In fact, this is very necessary to improve the accuracy of ventilator calibration. Therefore, the author proposed a research entitled "Measurement Analysis of Inspiratory Minute Volume (mVi) and Expiratory Minute Volume (mVe) Parameters Using Flow Analyzer Design with Volume Control Ventilation (VCV) Mode on Ventilator". This study aims to develop a low-cost flow analyzer capable of measuring mVi and mVe parameters with Volume Control Ventilation (VCV) mode precisely, so as to validate ventilator performance according to clinical standards. The results of this study are expected to help medical personnel ensure that ventilators work optimally and according to specifications, support the care of patients with respiratory disorders, and add insight into the development of ventilator calibration devices that are still rarely studied. The implication is that this flow analyzer allows healthcare facilities with limited budgets to access advanced technology for ventilator calibration, while reducing the risk of setting errors that can lead to patient health complications.

2. MATERIALS AND METHOD

This research uses an AFM 3000 sensor to measure the air flow rate precisely, by converting the flow into digital data. The data is processed using an Arduino Uno powered by an 18650 battery, while the display uses a 3.2-inch Nextion screen. Data were collected using a calibrated Hamilton type C2 ventilator for comparison, with an I:E ratio setting of 1:2 and tidal volumes (VT) of 200 mL, 300 mL, 400 mL, 500 mL and 600 mL, each measured six times. This study also utilizes a bag valve mask as a substitute for the lungs to simulate breathing, in order to produce consistent and measurable airflow, making it easier to accurately test ventilator performance. The following block diagram is used to provide a clear visual description of the research flow, making it easier to understand the process and the relationship between the components involved.

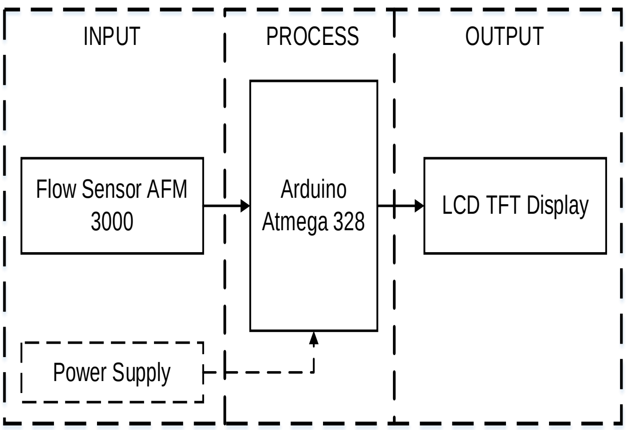

Fig. 1. Block Diagram Flow Analyzer

In Fig. 1 above is a block diagram of the flow analyzer. Feedback is received from the AFM 3000 flow sensor, which measures the air flow rate. This data is then processed by the Arduino Atmega 328 microcontroller to calculate and obtain the desired parameters. After the data is processed, the results of the Minute Volume (mVi) and Expiratory Minute Volume (mVe) measurements will be displayed on the TFT LCD screen, so that users can see the information visually and in real-time. In addition, there is also a power supply that functions as the main power supply source. The following is the design of data collection on this research tool, from the proposed design can be seen in Fig. 2 below.

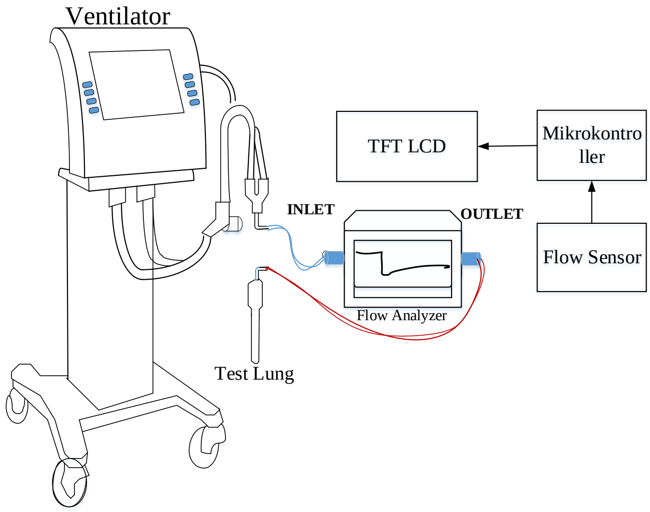

Fig. 2. Data Collection Method Using Ventilator

In Fig. 2 is a data collection method carried out using a Hamilton C2 brand ventilator. This ventilator is installed on the test lung to simulate human lungs. A flow analyzer is installed in series with a flow sensor on the ventilator and a test lung. With this arrangement, the air flowing from the ventilator to the test lung can be read by the flow analyzer. This flow rate data can then be calculated to obtain the required parameters.

In Fig. 3 is a flow chart of the flow analyzer. The process begins with a program to initialize the hardware, namely the flow sensor and TFT LCD. Once the initialization is complete, the program proceeds to the measurement stage. At this stage, the program checks whether the measurement process has started. If so, the program reads the airflow rate from the ventilator and processes the data obtained. This data processing aims to produce information that will be displayed at the next stage. If the measurement does not start, the program returns to the initialization step to ensure all hardware is ready for use. After the data is processed, the program displays the measurement value as well as a graph representing the airflow rate on the TFT LCD screen. The next step is to check if a reset is necessary. If a reset is required, the program returns to the airflow rate reading step to begin the remeasurement process. This cycle allows measurements to be repeated with the latest data each time a reset is performed. If no reset is required, the program will finish and stop all processes.

Corresponding author: Levana Forra, lep.forra@gmail.com , Department of Medical Electronics Technology, Poltekkes Kemenkes Surabaya, Jl. Pucang Jajar Timur No. 10, 60282, Surabaya
DOI: https://doi.org/10.35882/teknokes.v18i1.20

e-ISSN: 2407-8964
p-ISSN: 1907-7904

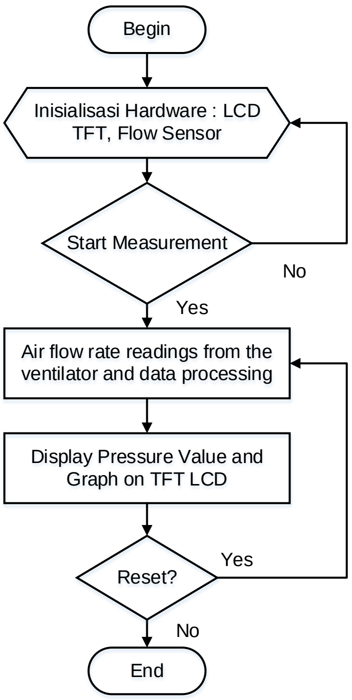

Fig. 3. Flow Analyzer Tool Flow Diagram

A. Data Analysis

In this study, measurements on each setting were made 5 times. That way, the average of the measurements can be searched using equations (1):

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

Where 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. Then, the standard deviation (stdev) value that indicates the degree (degree) of data group variation or standard size deviation from the mean can be searched using equation (2):

$$stdev = \sqrt{\frac{\sum_{i=1}^{n}(Xi-X)^2}{n-1}} \quad (2)$$

Where xi indicates the amount of the desired values, x indicates the average of the measurement results, and n shows the number of measurements. The % Error shows the error of the system. The lower value Error is the difference between the mean of each data. The error value is an error value that can be searched with equations (3):

$$Error\ \% = \frac{Data\ setting - average}{Data\ setting}\ x\ 100\% \quad (3)$$

Uncertainty Value (UA) indicating lack of definite knowledge of the measured value can be sought by equation (4):

$$UA = \frac{Stdev}{\sqrt{n}} \quad (4)$$

Where UA indicates the uncertainty value from the total measurement, SD shows the resulted standard deviation, and n shows the amount of measurement. And correction indicates the value added to compensate for the addition of errors can be searched with equations (5):

$$Correction = Mean - data\ setting \quad (5)$$

3. RESULTS

Data collection is carried out using the Volume control mode on the ventilator that has been installed as shown in Fig.2. The experiment was carried out 5 times with tidal volume settings of 200mL, 300mL, 400mL, 500mL, and 600ml and with an I:E ratio of 1:2 and a PEEP pressure of 5cmH2O. Subsequently, the module was readjusted and data was collected again with the results listed in Table 1 and Table 2 below:

Table 1. The Results of Data Collection from The Module Compared to The Readings on The Ventilator on The mVi Parameter

Inspiratory Minute Volume (mVi)								
No	Setting I:E	Tidal Volume	Ventilator	Module				
			Mean	Mean	error	Std	UA	Correction
1	1:02	200	2.54	2.66	-0.12	0.028	0.012	0.12
2	1:02	300	3.73	3.87	-0.14	0.162	0.072	0.14
3	1:02	400	5.10	5.22	-0.13	0.077	0.034	0.13
4	1:02	500	6.21	6.45	-0.24	0.118	0.053	0.24
5	1:02	600	6.27	5.59	0.69	1.351	0.604	-0.69

Corresponding author: Levana Forra, lep.forra@gmail.com , Department of Medical Electronics Technology, Poltekkes Kemenkes Surabaya, Jl. Pucang Jajar Timur No. 10, 60282, Surabaya
DOI: https://doi.org/10.35882/teknokes.v18i1.20

e-ISSN: 2407-8964
p-ISSN: 1907-7904

Table 1 above shows the results of data collection from the module compared to the readings on the ventilator on the mVi parameter. Because the ventilator does not have this parameter, mVi is calculated manually with the formula mVi=VTI×Respiration rate. The highest average error was seen in the tidal volume setting of 600 mL, with an error of 0.69. On the other hand, the lowest average error occurred in the 200 mL tidal volume setting, which showed an average error value of -0.12. In addition, the largest standard deviation was recorded at 1.351 in the 600 mL tidal volume setting, indicating that there was the most significant variation in the data.

Table 2. The Results of Data Collection from The Module Compared to The Readings on The Ventilator onThe mVe Parameter

Expiratory Minute Volume (mVe)								
No	Setting I:E	Tidal Volume	Ventilator	Module				
			Mean	Mean	error	Std	UA	Correction
1	1:02	200	2.26	2.27	-0.02	0.236	0.105	0.02
2	1:02	300	3.10	3.16	-0.07	0.258	0.116	0.07
3	1:02	400	4.50	4.56	-0.06	0.300	0.134	0.06
4	1:02	500	5.33	5.56	-0.23	0.490	0.219	0.23
5	1:02	600	5.65	5.65	0.00	0.478	0.214	0.00

Table 2 above presents the results of data collection from the module compared to the readings on the ventilator based on the mVe parameter. The 500 mL tidal volume setting showed the highest average error, which was -0.23. On the other hand, the 600 mL tidal volume setting recorded the lowest average error, which was 0. In addition, the largest standard deviation, 0.490, was recorded for the 500 mL tidal volume setting, indicating that it had the most significant variation in data.

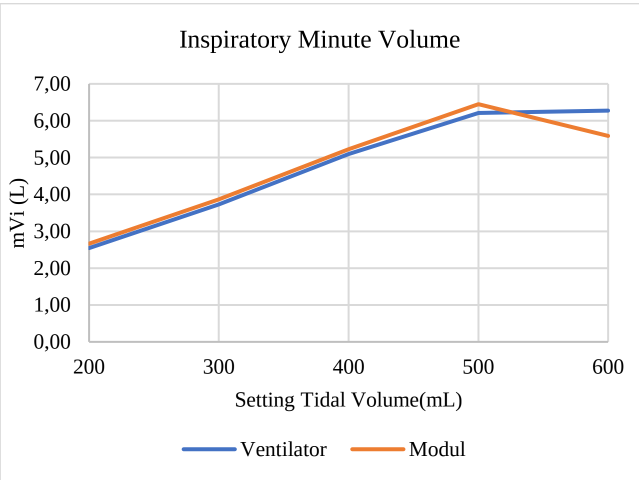

Fig. 4. Comparison Chart of mVi on Ventilator and Module at Setting Tidal Volume 200-600 mL

In Fig. 4 is a comparison graph of mVi on the ventilator and the module at Tidal Volume settings of 200-600 mL. based on the graph. The graph shows the comparison of Inspiratory Minute Volume (mVi) values between the ventilator and the Flow Analyzer module at various tidal volume settings (200 mL to 600 mL). At low tidal volume (200 mL), the module measurement results were almost identical to the ventilator, with a small average error of -0.12. However, as the tidal volume increased from 300 mL to 500 mL, there was a greater difference, with the error reaching -0.24. At a tidal volume of 600 mL.

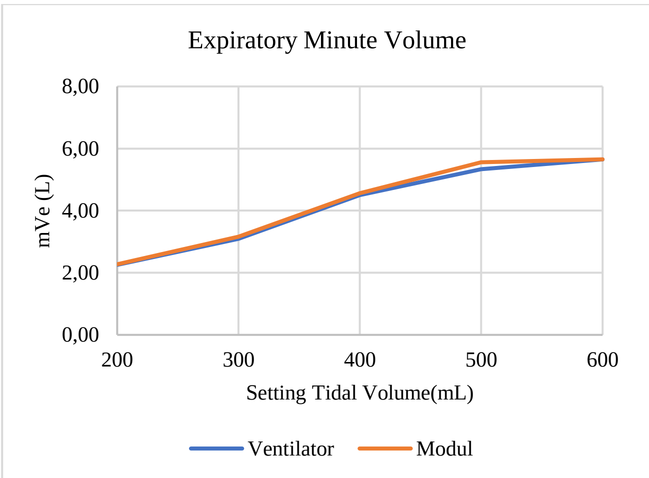

Fig. 5. Comparison Chart of mVe on Ventilator and Module at Setting Tidal Volume 200-600 mL

In Fig. 5 is a comparison graph of mVe on the ventilator and module at Tidal Volume settings of 200-600 mL. based on the graph. The graph shows the comparison of

Corresponding author: Levana Forra, lep.forra@gmail.com , Department of Medical Electronics Technology, Poltekkes Kemenkes Surabaya, Jl. Pucang Jajar Timur No. 10, 60282, Surabaya
DOI: https://doi.org/10.35882/teknokes.v18i1.20

Jurnal Teknokes
Homepage: teknokes.org; Vol. 18, No. 1, pp. 50-58, March 2025;
e-ISSN: 2407-8964
p-ISSN: 1907-7904

Expiratory Minute Volume (mVe) values between the ventilator as a reference and the Flow Analyzer module at tidal volume settings (200 mL to 600 mL). At low tidal volume (200 mL), the module's measurement results were almost the same as the ventilator, with a very small average error of -0.02, indicating excellent measurement accuracy. However, at medium to high tidal volume settings (300 mL to 500 mL), there was an increasing difference between the module and ventilator results, with the average error reaching -0.23 at a tidal volume of 500 mL. Meanwhile, at a tidal volume of 600 mL, the module mVe value was exactly the same as the ventilator (error 0.00).

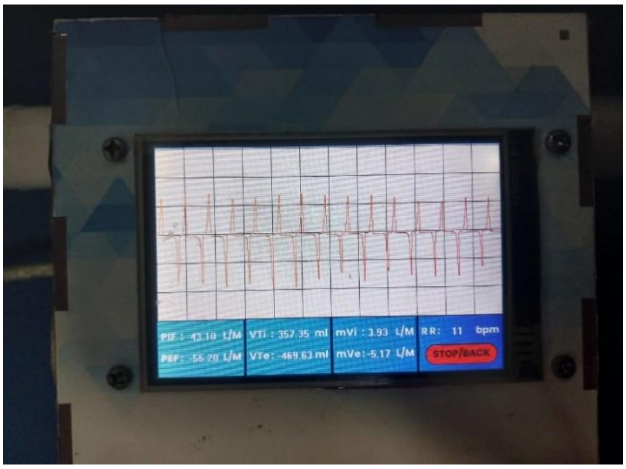

Fig. 6. Interface Display of Flow Analyzer Module

In Fig. 6 is the interface of the flow analyzer module. The display uses a TFT LCD screen on which graphs are displayed. In addition to the graph, this interface also displays a number of parameters, such as minute volume of inspiration (mVi) and minute volume of expiration (mVe).

4. DISCUSSION

The results showed that the tidal volume setting on the ventilator had a significant effect on the measurement accuracy of the tested parameters. The Inspiratory Minute Volume (mVi) parameter was calculated manually. The highest mean error for this parameter was recorded for the 600 mL tidal volume setting (0.69%), while the lowest mean error was found for the 200 mL setting (-0.12%). These results show that in this module, higher tidal volume settings tend to increase data variation, while lower tidal volume settings, such as 200 mL, are able to produce more accurate error values. The use of the AFM 3000 sensor in the Flow Analyzer proved to be effective for measurements on the ventilator. This study shows that the AFM 3000 sensor has the potential to be used as a flow sensor in the Flow Analyzer module, especially for the measurement of mVi and mVe parameters. Based on the measurement results, the highest error obtained was 0.23. This finding indicates that the sensor can be a key component in the development of a Flow Analyzer module at a more affordable cost, as done in this study.

Compared to the results of previous research by Abuzairi et al.[23], this research has the advantage that the display used is already in the form of a TFT LCD by displaying graphs and parameters. The parameters in this study also have mVi and mVe which previously did not exist in the study even though the parameters used in this study were fewer. Research by Jaroonrut Prinyakupt et al. developed a portable ventilator tester prototype by measuring parameters such as pressure, volume, and flow rate using an ESP-32 microcontroller and TFT LCD as the main display[26]. However, the study did not include Inspiratory Minute Volume (mVi) and Expiratory Minute Volume (mVe) parameters. In contrast, our study measured parameters such as PIF, PEF, VTi, VTe, respiration rate, and specifically mVi and mVe, although it did not include pressure measurements, I:E ratio, or parameter graphs. In this study, we used the AFM3000 sensor which is more economical than the SFM3000 sensor used in previous studies. Our research has limitations in handling data variations at high tidal volume settings and has not implemented testing using a standard flow analyzer. In addition, the parameters used are still limited to flow without involving pressure measurements. Therefore, future research is expected to focus on testing with a standard flow analyzer as well as adding parameters that are relevant for ventilator testing.

5. CONCLUSION

The This study highlights the significant effect of tidal volume settings on the accuracy of mVi and mVe measurements using the flow analyzer module that has been made. At a tidal volume setting of 600 mL, the average error was recorded as 0.69 with a standard deviation of 1.351, while a tidal volume setting of 200 mL showed the most accurate results with an average error of -0.12. This finding suggests that low tidal volume settings, such as 200 mL, provide more consistent and accurate measurement results, while higher tidal volume settings tend to increase data variation. The use of the AFM 3000 sensor proved effective as a flow sensor in the Flow Analyzer module, especially for the measurement of mVi and mVe parameters. The results of this study indicate that this sensor is well suited for the development of a more economical and accurate Flow Analyzer module, thus increasing the accessibility of this technology in clinical applications.

This study provides a basis for further studies to overcome limitations, such as the high variation of data at higher tidal volume settings and the lack of testing with a standard Flow Analyzer. Development of the module by adding additional parameters, such as pressure, and validation of its applicability in real clinical settings are recommended. These steps may improve the reliability and usability of the Flow Analyzer module, as well as drive innovation in respiratory care and ventilator calibration.

REFERENCES

[1] S. Silvestri, “The influence of flow rate on

Corresponding author: Levana Forra, lep.forra@gmail.com , Department of Medical Electronics Technology, Poltekkes Kemenkes Surabaya, Jl. Pucang Jajar Timur No. 10, 60282, Surabaya
DOI: https://doi.org/10.35882/teknokes.v18i1.20

breathing circuit compliance and tidal volume delivered to patients in mechanical ventilation," *Physiol. Meas.*, vol. 27, no. 1, pp. 23–33, 2006, doi: 10.1088/0967-3334/27/1/003.

[2] S. M. Ali, M. S. Mahmood, and N. S. Mahmood, "Design of a Low-Cost Ventilator to Support Breathing for Patients with Respiratory Failure Arising from COVID-19," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1067, no. 1, p. 012143, 2021, doi: 10.1088/1757-899x/1067/1/012143.

[3] W. Zhao, J. Zhang, M. E. Meadows, Y. Liu, T. Hua, and B. Fu, "A systematic approach is needed to contain COVID-19 globally," *Sci. Bull.*, vol. 65, no. 11, pp. 876–878, 2020, doi: 10.1016/j.scib.2020.03.024.

[4] A. V. Radogna, P. A. Siciliano, S. Sabina, E. Sabato, and S. Capone, "A low-cost breath analyzer module in domiciliary non-invasive mechanical ventilation for remote copd patient monitoring," *Sensors (Switzerland)*, vol. 20, no. 3, 2020, doi: 10.3390/s20030653.

[5] P. L. Silva and P. R. M. Rocco, "The basics of respiratory mechanics: ventilator-derived parameters," *Ann. Transl. Med.*, vol. 6, no. 19, pp. 376–376, 2018, doi: 10.21037/atm.2018.06.06.

[6] World Health Organization and Mission China Joint, "Report of the WHO-China Joint Mission on Coronavirus Disease 2019 (COVID-19)," *WHO-China Jt. Mission Coronavirus Dis. 2019*, vol. 2019, no. February, pp. 16–24, 2020.

[7] J. M. Pearce, "A review of open source ventilators for COVID-19 and future pandemics," *F1000Research*, vol. 9, no. May, 2020, doi: 10.12688/f1000research.22942.2.

[8] K. Iyengar, S. Bahl, Raju Vaishya, and A. Vaish, "Challenges and solutions in meeting up the urgent requirement of ventilators for COVID-19 patients," *Diabetes Metab. Syndr. Clin. Res. Rev.*, vol. 14, no. 4, pp. 499–501, 2020, doi: 10.1016/j.dsx.2020.04.048.

[9] A. S. Tran, H. Q. Thinh Ngo, V. K. Dong, and A. H. Vo, "Design, Control, Modeling, and Simulation of Mechanical Ventilator for Respiratory Support," *Math. Probl. Eng.*, vol. 2021, 2021, doi: 10.1155/2021/2499804.

[10] S. T. Venkataraman, *Mechanical Ventilation and Respiratory Care*, Fourth Edi. Elsevier, 2011. doi: 10.1016/B978-0-323-07307-3.10049-7.

[11] D. Wu, C. Wu, S. Zhang, and Y. Zhong, "Risk factors of ventilator-associated pneumonia in critically Ill patients," *Front. Pharmacol.*, vol. 10, no. MAY, pp. 1–7, 2019, doi: 10.3389/fphar.2019.00482.

[12] A. Abdelrazik Othman and M. Salah Abdelazim, "Ventilator-associated pneumonia in adult intensive care unit prevalence and complications," *Egypt. J. Crit. Care Med.*, vol. 5, no. 2, pp. 61–63, 2017, doi: 10.1016/j.ejccm.2017.06.001.

[13] F. Álvarez-Lerma and M. Sánchez García, "'The multimodal approach for ventilator-associated pneumonia prevention'—requirements for nationwide implementation," *Ann. Transl. Med.*, vol. 6, no. 21, pp. 420–420, 2018, doi: 10.21037/atm.2018.08.40.

[14] W. P. King *et al.*, "Emergency ventilator for COVID-19," *PLoS One*, vol. 15, no. 12 December, pp. 1–19, 2020, doi: 10.1371/journal.pone.0244963.

[15] R. L. Soiza, A. I. C. Donaldson, and P. K. Myint, "Vaccine against arteriosclerosis: an update," *Ther. Adv. Vaccines*, vol. 9, no. 6, pp. 259–261, 2018, doi: 10.1177/https.

[16] B. M. Ciurea, S. Kostrakievici, and M. I. Nistor, "Inspiratory and expiratory flow rates determination using a single spirolog type flow sensor," *2013 E-Health Bioeng. Conf. EHB 2013*, pp. 5–8, 2013, doi: 10.1109/EHB.2013.6707240.

[17] L. A. K. de Andrade and E. F. Manffra, "An additive manufacturing fabricated a split Pitot tube transducer for mechanical ventilator analyzers," *Res. Biomed. Eng.*, vol. 38, no. 1, pp. 317–324, 2022, doi: 10.1007/s42600-020-00121-4.

[18] C. T. Kor, K. H. Lin, C. H. Wang, J. F. Lin, and C. D. Kuo, "Ventilator parameters in the diagnosis and prognosis of acute respiratory distress syndrome in postoperative patients: A preliminary study," *Diagnostics*, vol. 11, no. 4, 2021, doi: 10.3390/diagnostics11040648.

[19] J. Beck and L. Fuentes, "Manual of Neonatal Respiratory Care," *Man. Neonatal Respir. Care*, 2017, doi: 10.1007/978-3-319-39839-6.

[20] P. G. Lee, C. M. Helsmoortel, S. M. Cohn, and M. P. Fink, "Are low tidal volumes safe?," *Chest*, vol. 97, no. 2, pp. 430–434, 1990, doi: 10.1378/chest.97.2.430.

[21] P. Gustin, M. Bakima, T. Art, P. Lekeux, F. Lomba, and K. P. van de Woestijne, "Pulmonary function values and growth in Belgian white and blue double-muscled cattle.," *Res. Vet. Sci.*, vol. 45, no. 3, pp. 405–410, 1988, doi: 10.1016/s0034-5288(18)30974-3.

[22] R. A. Pupella, "Mechanical ventilation in patient with respiratory failure," *Mech. Vent. Patient with Respir. Fail.*, pp. 1–148, 2017, doi: 10.1007/978-981-10-5340-5.

[23] T. Abuzairi, A. Irfan, and Basari, "COVENT-Tester:

Corresponding author: Levana Forra, lep.forra@gmail.com , Department of Medical Electronics Technology, Poltekkes Kemenkes Surabaya, Jl. Pucang Jajar Timur No. 10, 60282, Surabaya
DOI: https://doi.org/10.35882/teknokes.v18i1.20

A low-cost, open source ventilator tester," *HardwareX*, vol. 9, p. e00196, 2021, doi: 10.1016/j.ohx.2021.e00196.

[24] A. Von Chong *et al.*, "Low-cost, rapidly deployable emergency mechanical ventilators during the COVID-19 pandemic in a developing country: Comparing development feasibility between bag-valve and positive airway pressure designs," in *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS*, 2021, pp. 7629–7635. doi: 10.1109/EMBC46164.2021.9630676.

[25] J. Alsalaet *et al.*, "Laminar flowmeter for mechanical ventilator: Manufacturing challenge of Covid-19 pandemic," *Flow Meas. Instrum.*, vol. 82, Dec. 2021, doi: 10.1016/j.flowmeasinst.2021.102058.

[26] J. Prinyakupt and K. Rungprasert, "The portable ventilator tester," *Int. J. Appl. Biomed. Eng.*, vol. 14, no. 1, pp. 37–43, 2021.

AUTHOR BIOGRAPHY

Levana Forra Wakidi received her M.T from Institut Teknologi Sepuluh Nopember (ITS) Surabaya Indonesia in 2018, She was appointed as an Assistant Lecturer since 2020. and became a Lecturer in 2023 and teaches at the Health Polytechnic of the Ministry of Health Surabaya Indonesia. The courses taught are Basic Biomedical Sciences, Transducer Sensors, Clinical Laboratory Equipment and Life Support Equipment. Her research interests include Life Support, Medical Instrumentation Engineering, She is also active as an IKATEMI (Indonesian Electromedical Association) board member. This organization aims to improve the professionalism of electromedical technicians and medical technology in Indonesia.She can be contacted via email: lep.forra@gmail.com

Farid Amrinsani He took Diploma III Electromedical Technology, Diploma IV Electromedical Technology, Electrical Engineering, Master of Applied Engineering at Surabaya State Electronics Polytechnic, as an educational staff in the field of basic electronics and programmed devices at the Department of Electromedical Technology of the Surabaya Ministry of Health Polytechnic. Other Tridarma activities carried out are carrying out community service activities and conducting research activities. Currently, he is also active as an IKATEMI (Indonesian Electromedical Association) board member. This organization aims to improve the professionalism of electromedical technicians and medical technology in Indonesia.

Alfi Nur Zeha Active student majoring in Electromedical Engineering Technology at the Health Polytechnic of the Ministry of Health of the Republic of Indonesia, Surabaya, Indonesia. Her research interests include biomedical signal processing and analysis, sensor transducers, and Telemedicine applications.

Riqqah Dewiningrum Active student majoring in Electromedical Engineering Technology at the Health Polytechnic of the Ministry of Health of the Republic of Indonesia, Surabaya, Indonesia. Her research interests include biomedical signal processing and analysis, sensor transducers, and Telemedicine applications.

Corresponding author: Levana Forra, lep.forra@gmail.com , Department of Medical Electronics Technology, Poltekkes Kemenkes Surabaya, Jl. Pucang Jajar Timur No. 10, 60282, Surabaya
DOI: https://doi.org/10.35882/teknokes.v18i1.20

e-ISSN: 2407-8964
p-ISSN: 1907-7904

Corresponding author: Levana Forra, lep.forra@gmail.com , Department of Medical Electronics Technology, Poltekkes Kemenkes Surabaya, Jl. Pucang Jajar Timur No. 10, 60282, Surabaya
DOI: https://doi.org/10.35882/teknokes.v18i1.20