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Design and Implementation of Microcontroller Based Oxygen Purification and Sterilization Using Pressure Swing Adsorption Method

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Abstract

The COVID-19 pandemic, caused by the SARS-CoV-2 virus, has increased the demand for oxygen on a global scale. Oxygen is especially needed for the treatment of COVID-19 patients who have difficulty breathing or who have severe acute respiratory distress syndrome (ARDS). Oxygen purifiers play an important role in providing supplemental oxygen to patients who need it. Oxygen purifiers can be used to remove contaminants and other harmful substances from oxygen, thereby producing safe and clean oxygen for a variety of applications. In this study, we made an oxygen purifier using 1 unit of electric compressor motor free of lubricant or oil, 2 units of filter media containing 13X zeolite media and an air valve (solenoid valve) which is controlled by a microcontroller via an 8 channel relay module and monitored by LCD 20X4 via Oxygen sensor type OOM202. The results of our research are in the form of a device that can produce an oxygen gas output purity of 70.09% with a reading accuracy of 0.04% at a production of 0

to 5 liters per minute with a system operating pressure of 30 psi (2,068 Bar).

Keywords

Portable oxygen purifier, microcontroller, pressure swing adsorption

Introduction

Oxygen is one of the most abundant elements in the universe. Oxygen is an important element in physics and chemistry (Nagy, 2011). Oxygen (O_2) is needed by cells to convert glucose into energy needed to carry out various activities, such as physical activity, absorption of food, building immunity, restoring body condition, and destroying some toxic waste products of metabolism (Vander Heiden, 2009).

Fulfilling the need for oxygen is the most important material because it aims to ensure the ongoing processes of cell metabolism in the body, maintain life and carry out organ and cell activities (Murphy, 2011).

Oxygen (O_2) is a gas component and a vital element in metabolic processes. Oxygen plays an important role in all functional body processes and the need for oxygen is the most important and very vital requirement for the body.

Oxygen therapy (O_2) or supplemental oxygenation is the offering of medical oxygen (O_2) as part of the action of a therapeutic drug. Medical oxygen (O_2) has a content of at least 82%. Common sources of oxygen are: oxygen generating machines and tanks (O_2) liquid oxygen storage (O_2) and oxygen concentrators (O_2). The oxygen concentrator work like air purifier (Hirani, 2021)

The need for medical oxygen (O_2) is soaring along with the increase in COVID-19 cases, even in some areas there have been reports of a shortage of stock. Responding to this, Minister of Health Budi Gunadi Sadikin said that currently the government is maximizing the national oxygen production capacity (O_2). So that it can be diverted to meet medical needs.

Based on the research that has been developed, this research will discuss an oxygen purifier system with an easy-to-use design with LCD components as a monitor in the control system and communication between the user and the control unit, as well as oxygen component (O_2) sensors or what is commonly called O_2 Cell as an indicator to determine the level of purity of an Oxygen gas produced by a portable oxygen concentrator unit (O_2).

2. Experimental Apparatus and Mathematical Model

2.1. Experimental Apparatus

Pressure swing adsorption (PSA) is a technology used to differentiate certain gases from a mixture of gases under pressure according to the molecular characteristics of the species and their affinity for the adsorbent material. It operates at nearly the same temperature as our ambient (ambient) air. Special adsorbents (eg zeolite, activated carbon, molecular sieves, etc.) are used as traps, which preferentially adsorb gaseous target species at elevated pressures. The process is then subjected to low pressure to remove the adsorbed material.

Pressure swing adsorption processes take advantage of the fact that under high pressure, gases tend to be attracted to solid surfaces, or "adsorbed". The higher the pressure, the more gas is adsorbed. When the pressure is reduced, the gas is reduced, or absorption. The PSA process can be used to separate gases in a mixture because different gases tend to be attracted to different solid surfaces more or less strongly. The simple formula for calculating the flow rate for each time is:

$$Target\ FiO_2 = \frac{FiO_2 L/\min\ (udara\ L/min\ x\ 21\%)}{Total\ flow, L/min}$$

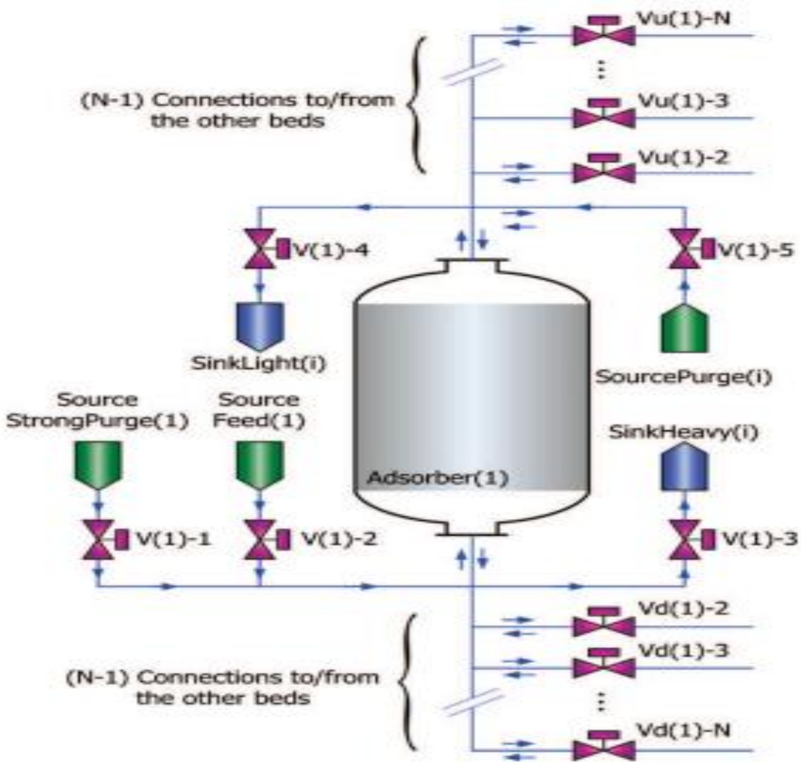

Figure 1 Original Multiple PSA Approach (Nikolic, 2009)

2.2. Research setup

This oxygen concentrator unit can monitor the results of oxygen gas production which is designed to address patient needs with data information on oxygen levels needed by patients in a measurable manner using the OOM 202 Oxygen sensor and ADS 1115 ADC converter which is displayed by the 20X4 LCD.

The block diagram below explains that the process begins with the power source or power supply unit providing voltage to the microcontroller and the common relay in the relay module, when the microcontroller module is functioning on or running, the LCD display monitor will display the Oxygen concentrator value at the same time as the relay module connects electricity to turn on air compressor motors and solenoid valve control systems or electric valves in pneumatic installations automatically, so that the airflow process can be controlled according to the program data on the microcontroller

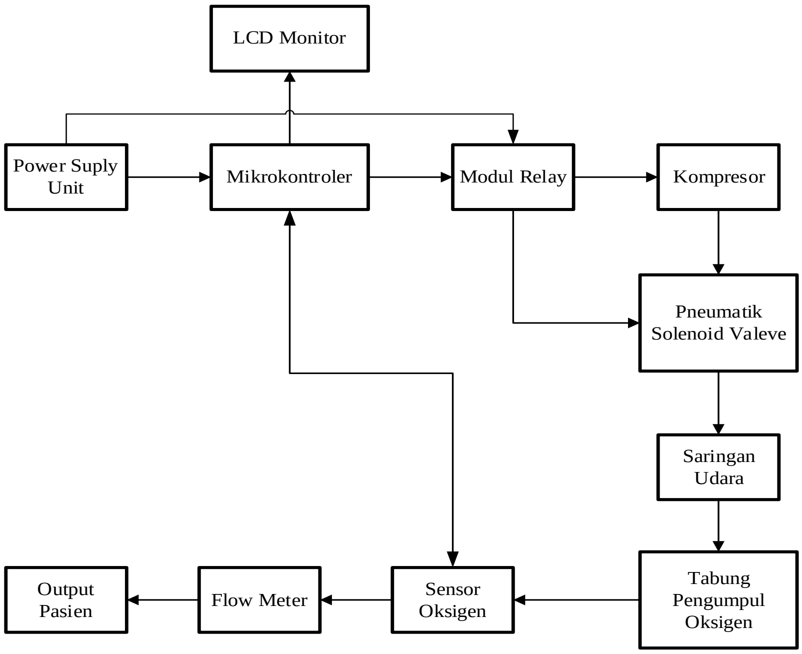

Figure 2. Diagram Block of System

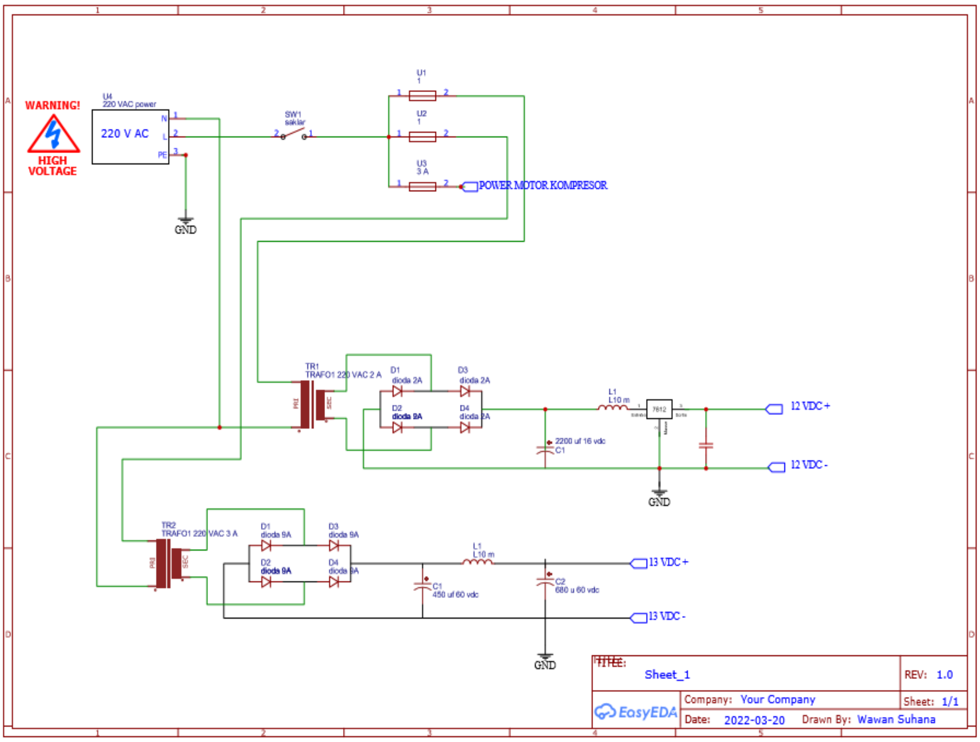

Figure 3. Power Supply Schematic of system

The picture below describes a series of several modules that are assembled into a single control system that can be monitored on the LCD monitor display with a display area of 20 characters with 4 columns (20 X 4). AT MEGA 382 PU microcontroller IC, this circuit will control several systems including:

1. Monitoring System
2. Oxygen Sensor System
3. Pneumatic PSA (Pressure Swing Adsorption) System

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4. Cooling System.

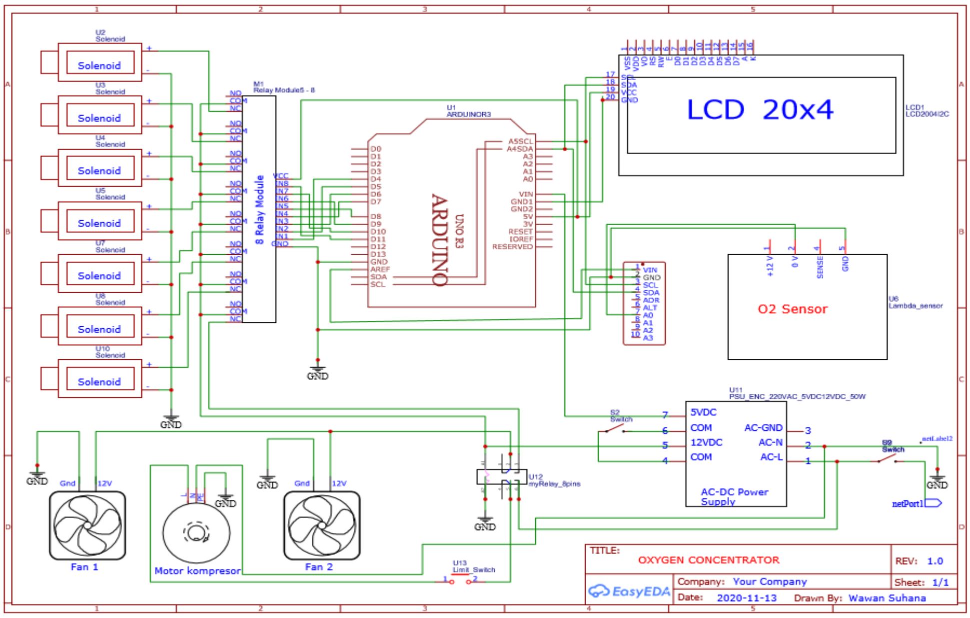

Figure 4. Schematic of Portable Oxygen Concentrator Controller Circuit

In the air screening process the author uses the PSA (Pressure swing adsorption) system which has been described previously. The pressure swing adsorption process utilizes the air condition in the filter tube under high pressure, the gas tends to be attracted to the solid surface, or "adsorbed". The higher the pressure, the more gas is adsorbed. When the pressure is reduced, the gas is released, or absorbed. In the PSA process it is used to separate gases in a mixture because the different gases tend to be attracted to the solid surface.

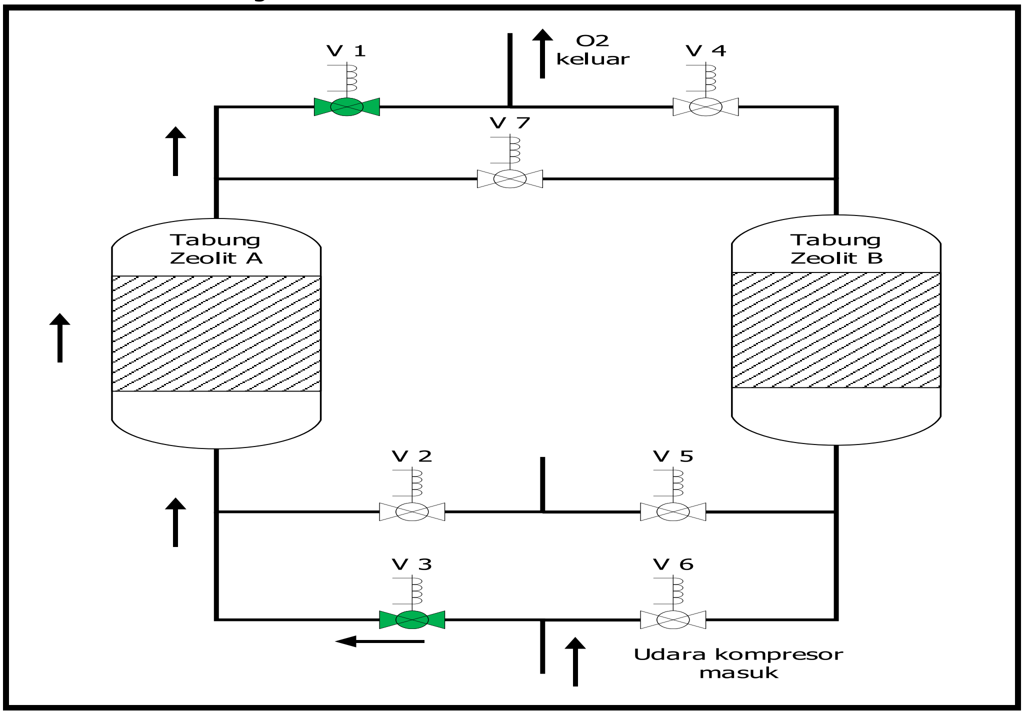

Figure 5. Schematic of Portable Oxygen Concentrator Controller Circuit Air flow diagram of Pressure Swing Adsorption phase 1

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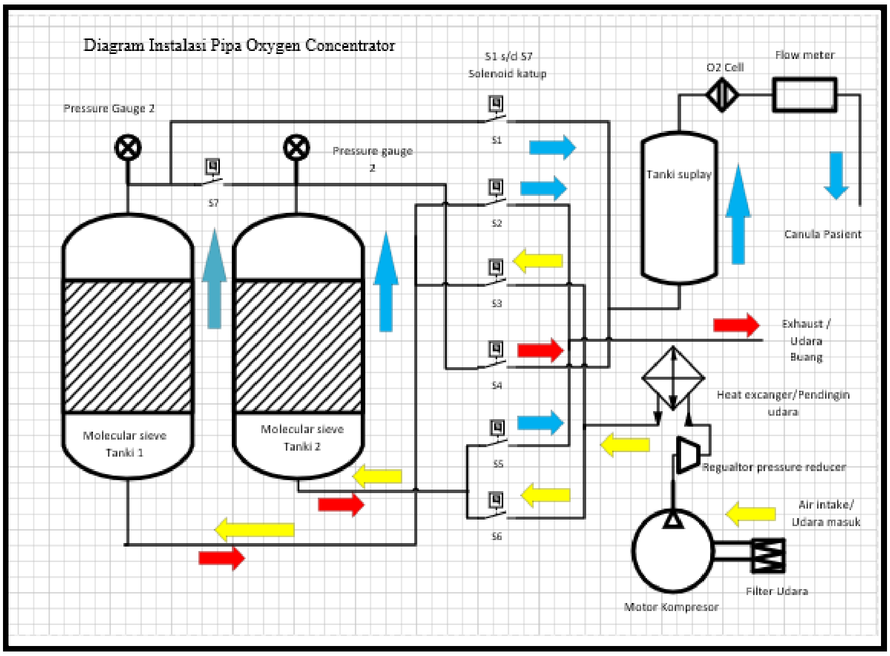


Figure 6. Pneumatic portable oxygen concentrator pipe installation diagram

2.3. Research Methodology

Figure 7 explains the flow chat of the system. The analysis is carried out by comparing the oxygen sensor object and the Oxygen Concentrator object with the standard Oxygen Analyzer type Max O_{2+} tool. the test value is taken equal to the value of open air in a room.

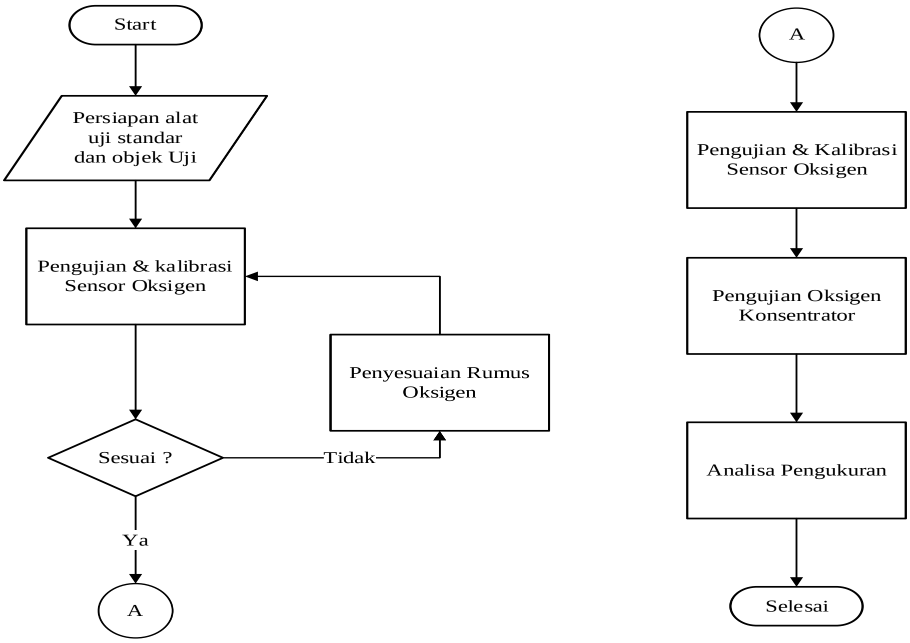


Figure 7. The flow chart system

Furthermore, the testing pure oxygen concentrator is carried out by comparing air samples coming out of the flowmeter humidifier's oxygen gas output with the probe sensor, a standard oxygen analyzer calibration tool.

The test was carried out by measuring 5 test samples. Each test sample was carried out 5 times the measurement experiment. The measurement results will be compared between the two measuring instruments used. To facilitate testing, a table is made as below. After testing and measuring, the data obtained will be analyzed so that the error, accuracy and precision values can be determined.

3. Results

3.1. Portable Oxygen Purifier Design Assembly

Design assembly begins with preparing the unit housing and layout the position of each component or hardware that has been recorded and checked according to its function so that the available space in the unit housing can be installed neatly. Assembling a portable oxygen concentrator design air filter starts from connect a pressure gauge or analog air pressure gauge to the filter housing cover and pneumatic fittings or pneumatic pipe fittings for pneumatic pipe connection fittings the output is installed on the filter housing lid and the input is attached to the bottom of the filter housing then the filter material or zeolite media is inserted into the housing Then the filter housing cover is attached to the top of the filter housing by attaching it to the thread already available in the filter housing.

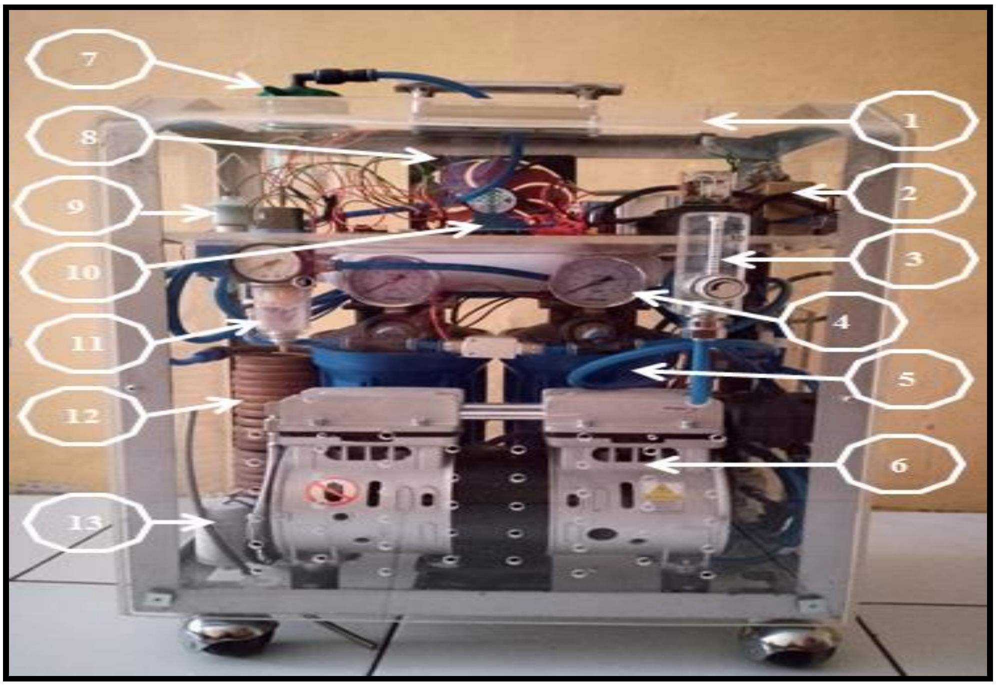


Figure 8. The flow chart system

Caption
1. Toggle type switch
2. PSU (Power Supply Unit) Adapter Circuit
3. Oxygen flow meter
4. Pressure Gauge or pressure gauge
5. Air Filter
6. Compressor Motors
7. Oxygen Output on Hunidifier

8. Cooling fan
9. Oxygen sensors
10. Controller Module or microcontroller
11. Water trap filter (water trap filter)
12. Air conditioning pipe (Heat sink)
13. Ac Motor Compressor Capacitor

Performance testing of portable oxygen concentrator design oxygen sensor testing

Oxygen sensor testing was carried out to find out the value of the sensor by comparing it with a standard measuring instrument, namely the oxygen analyzer type max o2+ with the air around the test room, measurement experiments were only carried out on 8 trials for 40 minutes with a duration of about 5 minutes each time.

Table 1. Oxygen Sensor Testing on Portable Oxygen Concentrator Design

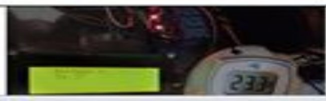
No.	oxygen sensor test object	oxygen sensor calibration	error	documentation
1	23.44 %	23.5 %	0.16 %	
2	24.45 %	23.3 %	1.15 %	
3	34.37 %	23.3 %	1.03 %	
4	23.44 %	23.5 %	0.06 %	
5	23.64 %	23.5 %	0.14 %	
6	23.44 %	23.5 %	0.06 %	
7	23.37 %	23.3 %	0.07 %	
8	23.64 %	23.5 %	0.14 %	

Table 2. Average Value of Testing Objects and Test Equipment

the average value of the sensor test object	the average value of the sensor calibration	error
24,97 %	23,42 %	0,35%

The results of the experimental measurements in the room around the test used a standard calibration test tool for Oxygen type Max O_{2+} and obtained data for oxygen purity levels of 0 - 23.42% and obtained an average test object value of 24.97% an average standard test tool value of 23.42 % the average value difference is 0.35% due to the limitations of the existing test measuring instruments, the authors are only able to measure the oxygen level

3.2. Output Measurement of Portable Oxygen Purifier Design

In order to find out the output level of oxygen purity produced by the design of a portable oxygen concentrator device, it is necessary to test it so that it can be used as data, which then the data will be processed using the deviation formula and the standard deviation formula to become data that explains the oxygen purity content obtained from the air sieving process.

Table 3. Data of oxygen flow meter result

No	Flow meter output (L/min)	Purifier oxygen output measurement				
		Exp. 1 (%)	Exp. 2 (%)	Exp. 3 (%)	Average (%)	Deviation
1	1	68.91	60.27	68.32	65.83	1.2
2	2	68.32	68.71	68.91	68.53	0.7
3	3	67.74	68.91	70.09	68.91	0.02
4	4	69.90	69.50	69.93	69.77	0.04
5	5	68.72	69.31	69.90	69.31	0
	Average deviation					1.96
	Standar deviaton					0.018

The data in table 3 is an experimental measurement of oxygen gas output from a portable oxygen concentrator design with several set points as part of the data taken and there are several values that indicate the same value. This shows that there is a close relationship between the oxygen gas output values read by the sensor oxygen from data taken 3 times at an oxygen output flow of 5 levels of liters per minute. From the data taken, an average deviation error value of 1.96 and a standard deviation of 0.018 is obtained.

4. Discussion

4.1. Assembly of a Portable Purifier Design

Design assembly begins with preparing the unit housing and layout the position of each component or hardware that has been recorded and checked according to its function so that the available space in the unit housing can be installed neatly.

4.1.1 Assembly of a portable oxygen purifier air filter design

The assembly of a portable oxygen concentrator design air filter starts from connecting a pressure gauge or analog air pressure gauge to the filter housing cover and pneumatic fittings or pneumatic pipe connections for pneumatic pipe connection fittings. filter material or zeolite media is inserted into the filter housing, then the filter housing cover is attached to the top of the filter housing by attaching it to the thread already available in the filter housing.

Figure 9. Air filter assembly

Information

1. Oxygen Pressure Gauge (Pressure Gauge)
2. 8 mm Pneumatic Output Connection
3. Close the Filter Housing
4. Hepa Filters
5. Sieve House

4.1.2 Air filter leakage test

The air filter test aims to ensure that there are no air or gas leaks in the portable oxygen concentrator filter that has been packed and tightened. Approximately 15 minutes until it is certain that the pressure gauge needle does not drop from the air pressure of approximately 3 bar.

Figure 10. Air filter leakage test

4.1.3 Assembly of the electric air valve (solenoid valve)

The design of an electric air valve (solenoid valve) system is an important part in regulating air flow in a pneumatic system by assembling 6 1-way type solenoid valves and 1 two-way type solenoid valve equipped with 5 fittings or connections. the 3-way pneumatic pipe is then combined with an 8 mm pneumatic pipe to form a unified air valve system as shown in the image below

Figure 11. Electric air valve system assembly design

Information

1. 8mm 3 Way Pneumatic Connection
2. Air Valve (Pneumatic solenoid valve 1Way) 8 mm
3. Pneumatic Pipe 8 mm

4.1.4 Assembly of Portable Oxygen Concentrator Design

After combining several systems and several components in the design of the tool above, a single unit is formed which has become a portable oxygen concentrator as shown below

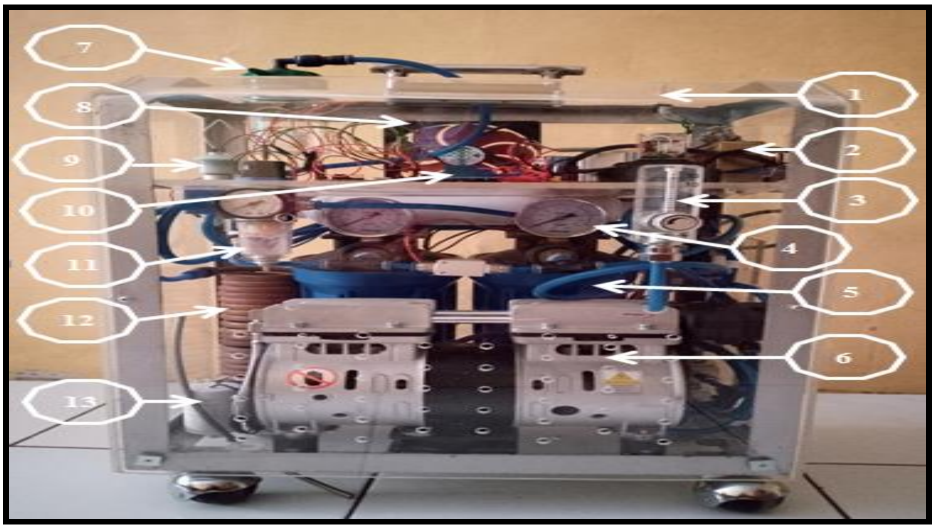


Figure 12. Portable oxygen purifier design

Information

1. Toggle type switch
2. PSU (Power Supply Unit) Adapter Circuit
3. Oxygen flow meter
4. Pressure Gauge or pressure gauge
5. Air Filter
6. Compressor Motors
7. Oxygen Output on Humidifier
8. Cooling fan
9. Oxygen sensors
10. Controller Module or microcontroller
11. Water trap filter (water trap filter)
12. Air conditioning pipe (Heat sink)
13. Ac Motor Compressor Capacitor

5. Conclusion

The design of the oxygen purifier has produced an output value of oxygen purity of 70.09% with a production capacity of 5 liters/minute and a system operating pressure of 30 psi. Besides that the accuracy of sensor readings is 0.04%. The results are still below the permissible value, namely the minimum standard of 90% at the level of oxygen purity by the regulation of the Ministry of Health of the Republic of Indonesia No. 4 of 2016 concerning the use of medical gas and medical vacuum in health care facilities. However the production level, pressure and accuracy of sensor readings meet the criteria for mass-produced oxygen purifiers

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