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Intitulé

Study and design of a medical oxygen concentrator control board

Soutenu le : …………………………

Devant le Jury composé de :

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Abstract:

This project involves the development of an oxygen concentrator control board with additional features, such as wireless control via a smartphone and integration of an oximeter to measure oxygen saturation and heart rate. The main objectives are to design and implement a robust and efficient oxygen concentrator control board system, improve and understanding of the technology, provide better design standards and help healthcare technology. By integrating wireless and oximetry capabilities, the project aims to improve functionality and comfort for patients and healthcare professionals, as well as the efficiency and ease of use of the oxygen concentrator.

Résumé:

Ce projet porte sur le développement d'une carte de commande de concentrateur d'oxygène dotée de fonctionnalités supplémentaires, telles que la commande sans fil via un smartphone et l'intégration d'un oxymètre pour mesurer la saturation en oxygène et la fréquence cardiaque. Les principaux objectifs sont de développer et de mettre en œuvre un système de carte de contrôle de concentrateur d'oxygène robuste et efficace, d'améliorer la compréhension de la technologie, de fournir de meilleures normes de conception et d'aider la technologie des soins de santé. En intégrant des capacités sans fil et d'oxymétrie, le projet vise à améliorer la fonctionnalité et le confort pour les patients et les professionnels de la santé, ainsi que l'efficacité et la facilité d'utilisation du concentrateur d'oxygène.

ملخص :

يتضمن هذا المشروع تطوير لوحة تحكم مُكثّف أوكسجين بوظائف إضافية ، مثل التحكم اللاسلكي عبر الهاتف الذكي ودمج مقياس التأكسج لقياس تشبع الأكسجين ومعدل ضربات القلب. تتمثل الأهداف الرئيسية في تطوير وتنفيذ نظام لوحة تحكم مُكثّف أوكسجين قوي وفعال ، وفهم التكنولوجيا المستخدمة ، وتوفير معايير تصميم أفضل ودعم تكنولوجيا الرعاية الصحية. من خلال دمج إمكانات اللاسلكي وقياس التأكسج ، يهدف المشروع إلى تحسين الوظائف والراحة للمرضى والمتخصصين في الرعاية الصحية ، فضلاً عن كفاءة مُكثّف الأكسجين وسهولة الاستخدام.

Acknowledgement

First of all, we thank Allah for giving us the patience and strength to produce this humble work. It is an honor for us to be able to thank all those who helped us in any way to make it possible.

Our deepest gratitude and most heartfelt thanks go to our thesis supervisor, Mr. Seif Eddine AZOUG. We would like to thank him for the trust he placed in us, which encouraged us to work hard to live up to his expectations. We hope that you will find in this work a sincere gratitude for all the knowledge you have brought us during our time of study, with as much enthusiasm as you have done for us.

We'd like to thank you for the dynamism, competence and rigor you brought to our work. Many thanks to you for the quality of your supervision, your incredible availability and your invaluable advice.

We extend our heartfelt gratitude to the esteemed members of the jury, Mr. Messaoudene Idris, Mr. Azoug Seifeddine, and Mr. Abed Tarek, for their guidance and support throughout our academic journey. Their recognition of our work is deeply appreciated. Thank you for honoring us and for the opportunity to present our project.

I would like to thank Dr TALBI BILLEL for his help with the electrical side of the PSA process configuration used in this work. He was extremely helpful in providing the necessary improvements to the device to enable me to carry out the experiments I wished to perform.

Words cannot express our deepest gratitude to our parents for their priceless support and help along the way. for their invaluable support and help during our long years of study.

Dedication

To my family, whose confidence in me has been my constant motivation. Your support has been the foundation on which I have built my academic success.

I dedicate this work to all the people who have supported and encouraged me throughout my journey with PSA oxygen concentrators.

To my mentors and teachers, who guided and pushed me to explore the field of PSA technology. Your guidance and expertise have shaped my understanding and inspired my passion for this remarkable technology.

To my friends and classmates, who have shared both the triumphs and hardships of this journey. Your camaraderie and support have made the challenges more manageable and the successes more meaningful.

To the patients whose lives are touched by the advances in PSA oxygen concentrators. Your resilience and strength reminded me of the real impact this technology can have on improving healthcare outcomes.

With all my gratitude

K.T.Elhachemi

Dedication

This work is first dedicated to my parents whose faith in me never once wavered for their love, endless support and encouragement, also to my sisters, brothers. I further extend my gratitude to all members of BEKHTAOUI's family

I also dedicate this project to all my good friends for all the moments and memories shared together during the years spent in university, without forgetting my childhood friends for always having my back no matter the circumstances.

Last and not least, I dedicate this humble work to everyone who has taught, encouraged, and advised me during all my studies

BEKHTAOUI Fatiha

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Abbreviations

ADC Analog-to-Digital Conversion.

ARES Advanced Routing and Editing Software.

CAS Cryogenic Air Separation.

COPD chronic obstructive pulmonary disease.

EDR Enhanced Data Rate.

EMI Electromagnetic Interference.

FOSC Frequency of Oscillator.

GPIO General Purpose Input/Output.

HMI Human-Machine Interface.

HR Heart Rate.

I2C Inter-Integrated Circuit.

ICSP In circuit serial programming.

ISIS Intelligent Schematic Input System.

ISR interrupt service routine.

LCD Liquid crystal display.

LED Light emitting diode.

MAS Membranes Air Separation.

MCLR Master Clear.

MCU Microcontroller unit.

MSSP Master Synchronous Serial Port.

NTC Negative Temperature Coefficient.

PCB Printed circuit board.

PIC Peripheral Interface Controller.

POCs Portable oxygen concentrators.

PSA Pressure Swing Adsorption.

SMPS Switched Mode Power Supplies.

SpO2 Oxygen saturation.

SPP Serial Port Protocol.

USART universal synchronous asynchronous receiver transmitter.

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GENERAL INTRODUCTION

Oxygen is fundamental to our lives and plays an important role in many biological processes in the human body. It makes up about 21% of the earth's atmosphere and is necessary for breathing, energy production, brain function and physical performance. Oxygen is a fundamental element for life on Earth. **[1]**

An oxygen concentrator is a medical device designed to extract oxygen from environment air and provide concentrated oxygen gas to patients who require oxygen therapy. This device is used in the treatment of chronic obstructive pulmonary disease (COPD) or other lung diseases where the body's oxygen levels are too low. By providing patients with high-purity oxygen, an oxygen concentrator can help patients breathe easier and have a better quality of life. **[2]**

Oxygen concentrators work by filtering nitrogen, argon and other gases from the air and extracting oxygen at concentrations ranging from 87% to 95%. This oxygen is then administered to the patient via a nasal cannula or face mask. Oxygen concentrators are often preferred to traditional oxygen tanks because they do not need to be refilled, and are generally more cost-effective in the long term. **[2]**

Oxygen concentrators come in different sizes and capacities, ranging from portable units that can be carried by the patient to larger units that are used in hospitals and clinics. They require a power source usually electricity. **[2]**

The goal of this project is to develop and implement a system capable of producing oxygen using Pressure Swing Adsorption (PSA) technology. It will provide a stable and low-cost source of oxygen for medical facilities, hospitals, clinics, and individuals who require oxygen therapy. **[2]**

The first chapter reviews existing research on the principles of oxygen concentration and the different methods used in oxygen concentrators.

The second chapter focuses on the development of the oxygen concentrator control board, optimizing its components and design.

The final chapter covers simulation, implementation and testing, to ensure the design is properly validated and that any necessary adjustments are made to achieve optimum functionality and performance. These steps ensure the project's success in advancing oxygen concentrator technology.

CHAPTER I:

THEORETICAL STUDY OF THE PROJECT

1.1. Introduction

Oxygen is essential in many domains, such as medical, industrial and scientific domains. It can be generated in different ways using natural and industrial processes. **[1]**

In this chapter, we will review different air separation methods to produce oxygen such as the famous PSA (pressure swing adsorption) technology used by portable oxygen concentrators to provide high-purity oxygen for medical use.

1.2. Oxygen concentrators

1.2.1. Definition and usage

An oxygen concentrator is a medical device that extracts oxygen from the air by separating it from the rest of the air components (Nitrogen & Argon) using different air separation methods to provide a high-concentration oxygen purity**.**

It's a low-cost alternative to traditional oxygen tanks and cylinders **[3]**. They are used for medical purposes to provide supplemental oxygen to patients who require an oxygen therapy. They can be in an on-set station in medical facilities or a portable device called portable oxygen concentrator (POC) used at home providing a continuous and safe supply of oxygen to patients who need it. **[3]**

1.2.2. Concentrator vs. Generator

Oxygen concentrators and oxygen generators are two different types of technologies used to provide high purity oxygen but with different uses.

The term oxygen concentrator is used to describe a small portable oxygen concentrator (POC), while the term oxygen generator is used to describe a large device that produces large quantities of oxygen for industrial use. **[4]**

POC is a useful option for delivering oxygen because of their small size. However, their performance can be limited. The flow rate and total supply of oxygen may not be sufficient for emergency situations and service can be time consuming. **[4]**

On the other hand, an oxygen generator is a device that generates oxygen from a feed gas, usually compressed air, using a process called pressure swing adsorption (PSA) or membrane separation. Oxygen generators are used in industrial and medical applications. **[4]**

1.2.3. Advantages/Disadvantages

- **Advantages**

- **Mobility:** Many oxygen concentrators are portable, which allows patients to carry out their daily routine without getting fixed to an oxygen source. **[5]**
- **Utility:** Provide a continuous supply of oxygen without a refilling oxygen tank. **[5]**
- **Cost effective:** Low cost compared to traditional oxygen cylinders **[5]**

- **Disadvantages**

- **Limited flow:** may not be effective if patient requires very high oxygen flow. **[5]**
- **Noisy:** Some oxygen concentrators can be noisy when operating. **[5]**
- **Maintenance**: Requires regular maintenance (filter/zeolite replacement/cleaning).

1.3. Air separation methods

The atmosphere is composed mostly by nitrogen, oxygen, and argon as in figure 1.1. **[2]**

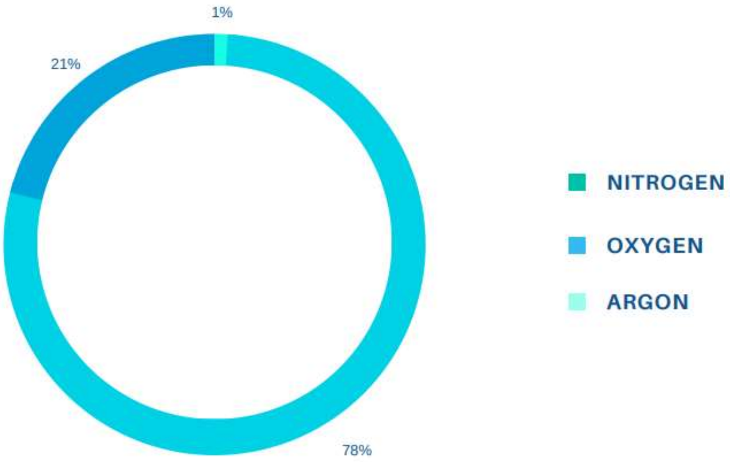


Figure1.1: Composition of the atmosphere gases.

To produce pure oxygen, oxygen concentrators use the following most common methods for separating oxygen from the rest of the elements of the air:

- Membranes Air Separation (MAS)
- Cryogenic Air Separation (CAS)
- Pressure swing adsorption (PSA)

1.3.1. Membranes Air Separation (MAS)

MAS is a process that separates oxygen from nitrogen and argon using specialized membranes as sown in figure 1.2 **[2]**.

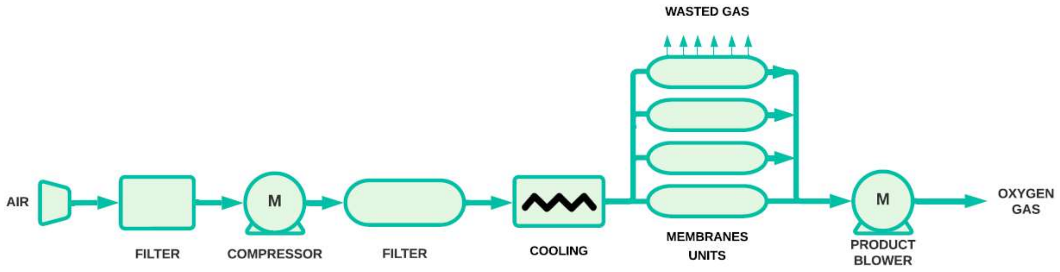


Figure1.2: Membranes Air Separation Flow Diagram.

First, atmospheric air is taken from the environment and passed through a filter to remove dust and water vapors. It is then compressed to increase its density and reduce its volume. As the air is compressed, its temperature increases and it passes through a cooling system to reduce its temperature. The next step is separation: the air passes through Membranes units that selectively allows oxygen molecules to pass through while blocking other gases, such as nitrogen and argon. Finally, the pure oxygen that passes through the membrane is collected and delivered to the user.

MAS method is highly efficient and provide a high level of oxygen purity and it is a cost-effective way to produce oxygen, but it requires a large surface area.**[2]**

1.3.2. Cryogenic Air Separation (CAS)

CAS methods are used when we need to produce large quantities of high purity oxygen. This process involves several steps as shown in figure 1.3. **[2]**

First, atmospheric air is taken from the environment and passed through a filter to remove dust and water vapors. It is then compressed to increase its density and reduce its volume. As the air is compressed, its temperature increases and it passes through a cooling system to reduce its temperature. The next step is to separate CO2, the air passes through a filter that allows the air to pass while blocking the CO2 gas, then the atmospheric air is cooled to a liquid state, before being passed to separate the different components including oxygen, nitrogen and argon.

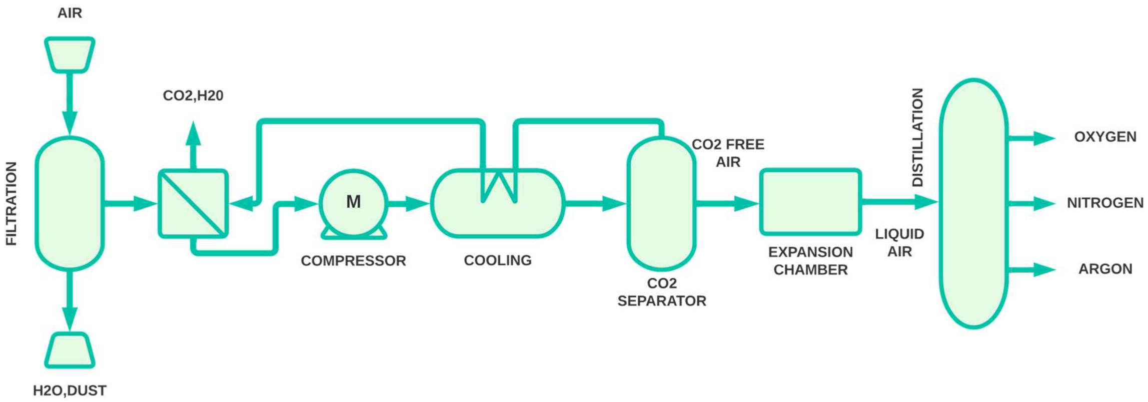


Figure1.3: Cryogenic Distillation Process Flow Diagram.

Because of its high efficiency, CAS method is the choice for medium- and large-scale oxygen production facilities. **[2]** One of the advantages of CAS method is the possibility of selling the components of the separated air in liquid form, with one liter of liquid oxygen equal to 860 liters of gas oxygen. This makes it a popular method of producing pure oxygen.

CAS method is not optimal for use in hospital because of the large and heavy equipment involved, and the safety risks associated with it. **[2]**

1.3.3. Pressure Swing Adsorption (PSA)

Pressure swing adsorption (PSA) is a widely used non-cryogenic air separation method for producing oxygen in medium capacity.

In PSA process, compressed air passes through a series of adsorption layers containing molecular sieves. A molecular sieve is a natural filter that selectively adsorb nitrogen and other particle, and allowing the oxygen to pass through and be collected. **[2]**

The two adsorption sieves alternate between the adsorption and desorption phases, ensuring a continuous supply of oxygen. The pure oxygen is then stored in a tank for later use as shown in figure 1.4. **[2]**

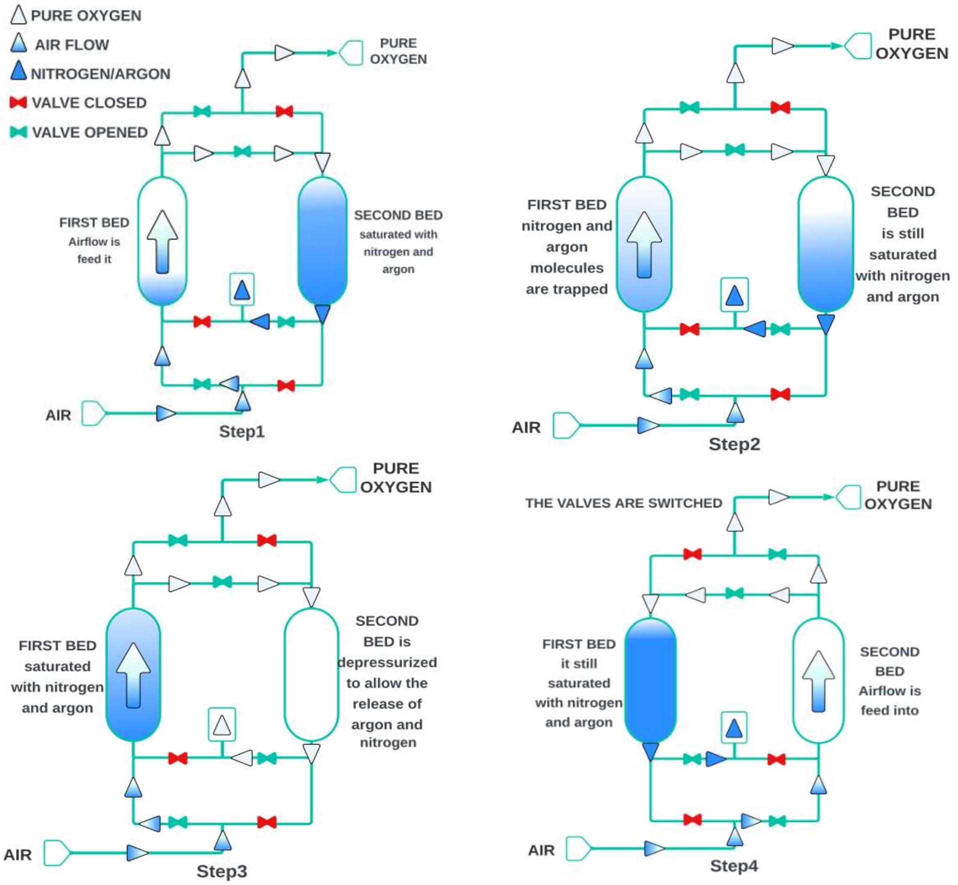


Figure1.4: Pressure Swing Adsorption Flow Diagram

Step 1: Airflow is feed into the first bed when the adsorbent in the second bed becomes saturated with nitrogen and argon. **[2]**

Step 2: Compressed air is fed into the first bed, where nitrogen and argon molecules are trapped, and oxygen is allowed to flow through. **[2]**

Step 3: The adsorbent in the first bed adsorbs nitrogen and argon, while the second bed is depressurized to allow the release of argon and nitrogen to the atmosphere. **[2]**

Step 4: When the first bed is saturated with nitrogen and argon and the second bed is cleaned, the process is repeated with compressed air fed into the second bed and the first bed depressurized to release the nitrogen and argon, providing a continuous flow of pure oxygen. **[2]**

PSA has many advantages over other methods, such as low energy consumption and high reliability. However, it is not ideal for large-scale oxygen production due to its limited capacity but it is very suitable for portable oxygen concentrators POC devices. **[2]**

1.4. Types of Molecular sieves

A molecular sieve is composed of special materials that has the ability to act as a natural filter at a molecular scale that selectively adsorb or block a particle and allow another one to pass through it **[2].** As there many materials with these properties, we will cover only Zeolite and Silica Gel that are often used in POC molecular sieves.

1.4.1. Silica Gel

Silica gel shown in figure 1.5 is used as a pre-treatment bed in POC devices to remove water vapor and dirt such as carbon dioxide and carbon monoxide before air enters the adsorption beds. However, water can stick to different sites on each zeolite, making them ineffective. Once the bed is saturated, it is heated with a heating coil to remove water. **[2]**

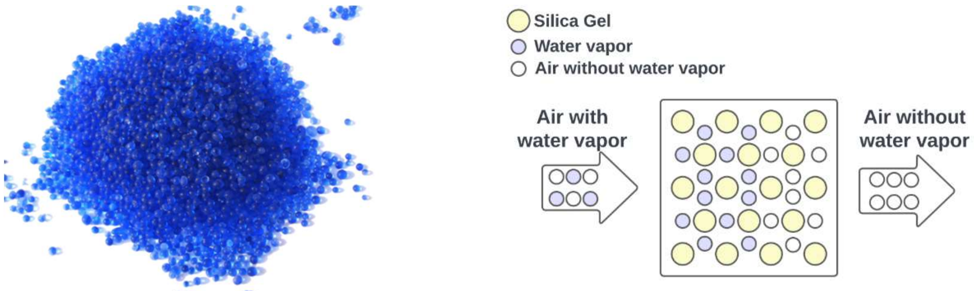


Figure1.5: Silica gel.

1.4.2. Zeolite

Zeolites are strongly absorbent structures composed of crystalline micropores as shown in figure 1.6.

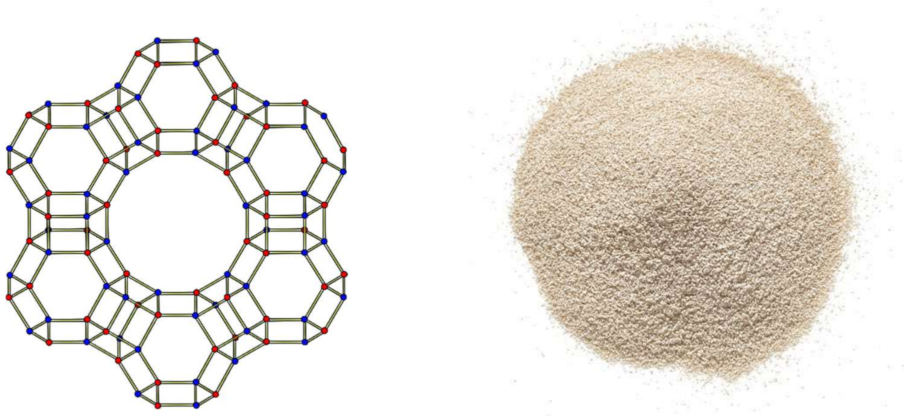


Figure1.6: Zeolite Structure.

Their selective molecular adsorption ability is based on their specific structures. **[2]** Different types of zeolites are able to adsorb specific types of molecules based on their unique pore structure, the size and the shape of the zeolite pores.**[2]**

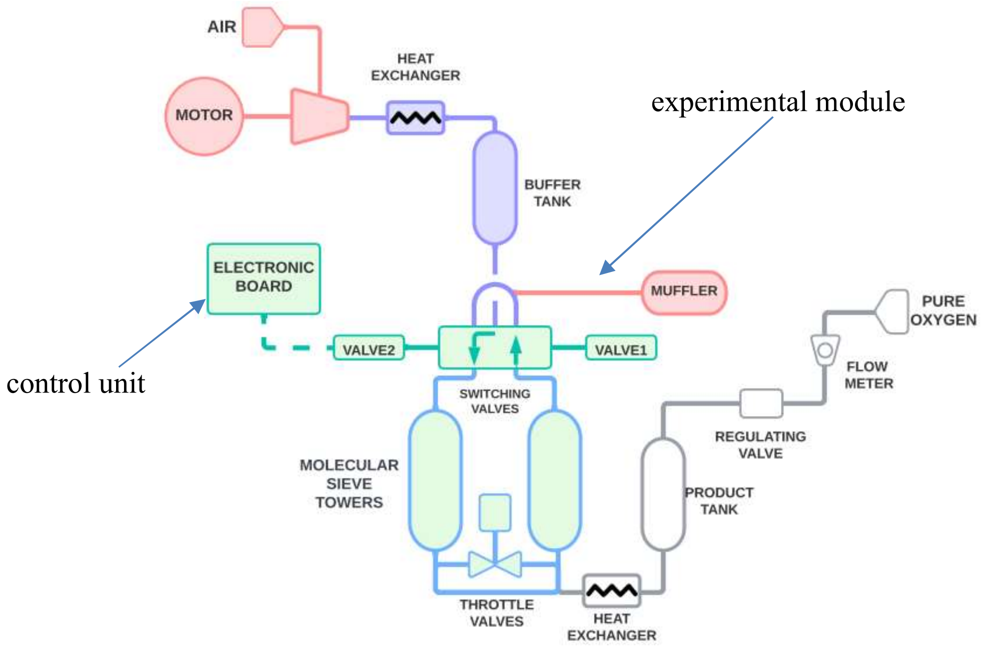
Zeolites are used in air separation processes because of their ability to control adsorption in different ways.

There are different zeolite types such as silver zeolites which are the most used in portable oxygen concentrators because of their ability to separate oxygen from nitrogen and argon more effectively. **[2]**

1.5. Portable oxygen concentrators based on PSA

1.5.1. Working principle

Portable oxygen concentrator POC it based on the use of PSA air separation method to produce pure oxygen. Figure1.7 shows a bloc diagram on how operates a portable oxygen concentrator based on PSA.



experimental module

control unit

Figure1.7: PSA Oxygen concentrator flow Diagram

We can divide it into two functional blocks

- An experimental module
- A control unit.

The experimental module is a device prepared to produce oxygen using PSA method and it is composed of **[6]:**

- A compressor with a dust filter
- Two electric valves
- Two adsorption towers filled with molecular sieve
- A product tank storing oxygen from the adsorption towers
- A pressure valve to reduce the high pressure of the oxygen to a lower pressure
- A flow meter that measures oxygen amount output in Liter/min.

In this module, the air taken from the environment is first passed through filter to remove dust and other solid substances. It enters the compressor to reach a high adsorption pressure. The air from the compressor is sent to the first adsorption column through the valve for a period of time determined by the control unit. The PSA process involves alternating cycles of adsorption and desorption. **[6]**

During the adsorption phase, oxygen is enriched by molecular sieve material in the column, while nitrogen is removed from the pressurized air. The enriched oxygen is partially stored in the product tank, while the sieve material gradually becomes saturated with nitrogen.

During the desorption phase, the compressed air is passed to the second adsorption column, and the first column is depressurized and regenerated by removing the absorbed nitrogen, carbon dioxide, and water vapor. Both cycles continue alternately to produce high-pressure oxygen for system output. **[6]**

1.6. Conclusion

In this chapter we presented existing air separation methods used to produce pure oxygen and we focused on the PSA method which is the best method suited for POC devices.

In addition, we reviewed in details how a POC device work to generate pure oxygen using the PSA method and molecular sieves based primarily on Zeolite as a particle filter to separate efficiently Oxygen from the rest of air particles.

Reviewing all these knowledges will help to understand the POC device’s electronic control board design proposed in the next chapter.

CHAPTER II:

PORTABLE OXYGEN CONCENTRATOR ELECTRONIC BOARD DESIGN

2.1. Introduction

The control board of an oxygen concentrator is an important component that manages the different functions of the device, such as the control of the oxygen flow, the display of oxygen levels, the time, the alarm system that ensures patient safety.

Designing a control board involves several steps, including selecting the microcontroller, designing the power supply circuit, developing the control algorithms, and using the sensors and actuators we need.

In this chapter we cover the essential steps that helped in the development of the oxygen concentrator device. Firstly, we will introduce the control circuit that completion of the project. then, will provide global details about the electronic board schematics proposed for this device ensuring its optimal performance.

2.2. Targeted POC

In this project, we intend to get back in service an old KONSUNG 10L/min portable oxygen concentrator POC. This POC is out of service due to a burned control board and a failing system. We aim to get it back in service by designing a new electronic control board.

The targeted POC interior/exterior is shown in figure 2.1:

- 220VAC Encased Free oil air compressor (ZEAW ZAZW700)
- 12VDC fan for cooling the air compressor
- Two 12VDC Electro valves for air flow control
- Molecular sieves towers filled with zeolite
- An oxygen Tank with a flow meter that can go up to a maximum of 10 L/min

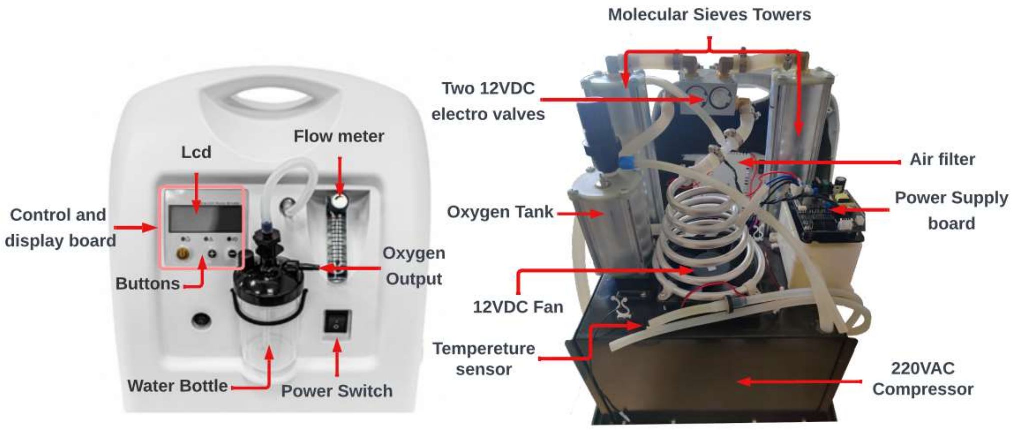


Figure 2.1: Target POC structure.

2.2.1. Free oil compressor

Oil-free compressors are commonly used in oxygen concentrators devices to ensure a clean, non-contaminated air supply. These compressors do not require oil for running, which reduces the risk of oil contamination of the oxygen produced.

Figure 2.2 shows the air compressor that is available in our targeted POC.

Figure 2.2: 220VAC Free oil compressor.

2.2.2. Cooling fan

A cooling fan is used to dissipate the heat generated during use, avoiding overheating and keeping the device running smoothly. The fans help the air to circulate and ensure the proper temperature inside the concentrator.

Figure 2.3: 12VDC Cooling fan.

2.2.3. Molecular sieves towers

Molecular sieves towers are shown in figure 2.4. They contain molecular sieves absorbent materials used for adsorption and separation processes - they come in different sizes and types. The targeted POC uses Zeolite as an adsorption material.

Figure 2.4: Molecular sieves towers.

2.2.4. Electro valves

The targeted POC uses two electric valves as shown in figure 2.5 operated by 12VDC solenoid coils to allow optimal control of the PSA by switching air flow between the two tower molecular sieves.

Figure 2.5: 12VDC Electro valves.

2.3. Project scope

In this project we intend to design a control board for the targeted portable oxygen concentrator POC that ensures the following functions:

- A controller based on an MCU that can drive it efficiently by regulating air flow in a pneumatic circuit comprising mainly an air compressor with two zeolite molecular sieves to output pure oxygen according to the PSA method seen in the previous chapter.
- A timer/programmer to offer the possibility to program POC start/stop time.
- An alarm system on compressor overheating/overpressure, power faults…etc.
- A battery backup system in case of power outage.
- An optional Bluetooth link to monitor and control the POC wirelessly
- An optional oximeter to measure patient blood oxygen saturation.
- An LCD display to show POC different status (total time, current time, temperature, pressure, oxygen saturation and heart rate).

We need also a power supply board to provide stable and safe power for:

- +5VDC: Control & display board
- +12VDC: Fan and electro valves
- 220VAC: Air compressor motor

Figure 2.6 shows the final project scope inspired from the KONSUNG POC manual.

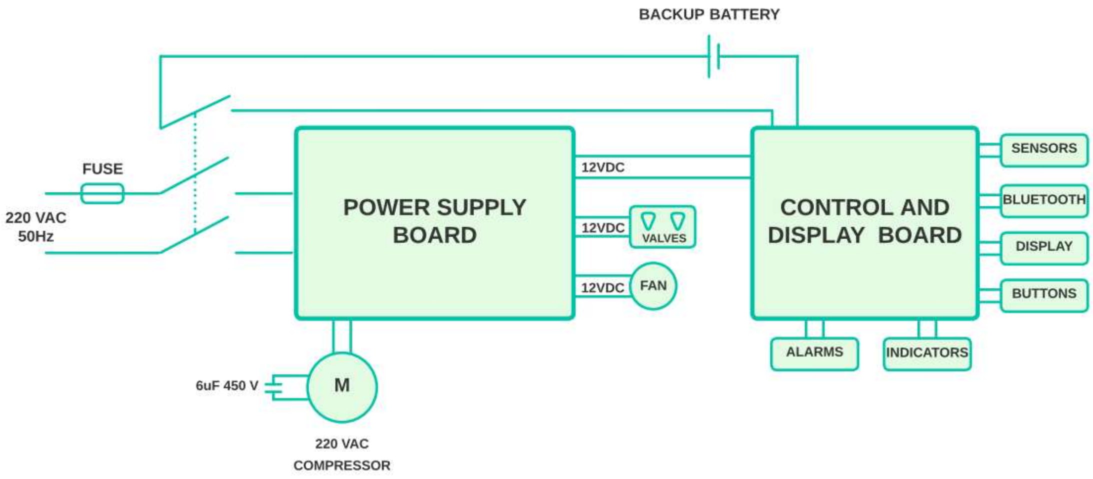


Figure 2.6: Project scope diagram.

2.4. Power supply board diagram

Figure 2.7 shows the power supply board bloc diagram.

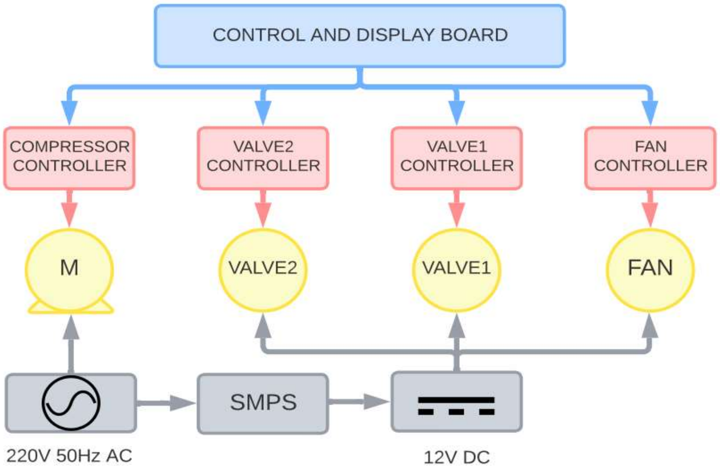


Figure 2.7: Power supply board bloc diagram.

For FAN/Valve1/Valve2 controllers are isolated from the main AC and DC by using optocouplers to ensure isolation between power supply circuit and the main board circuit.

We intend to design a switching mode power supply (SMPS) that provides a constant 12VDC output voltage. SMPS are a common type of power supply used in various types of electronic devices. Where linear power supplies adjust the voltage by dissipating extra energy as heat, SMPSs work by switching the input voltage quickly, converting it to the right output voltage with high performance.

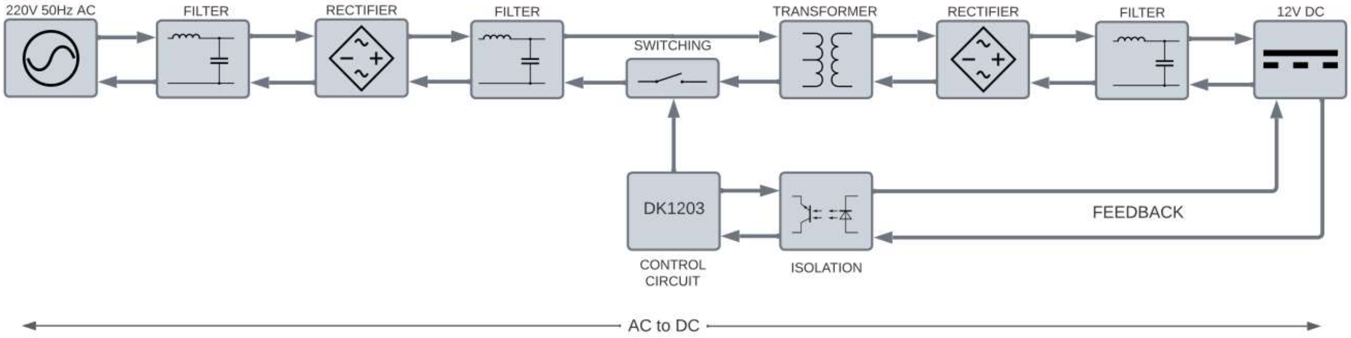


Figure 2.8: SMPS power supply bloc diagram.

As shown in figure 2.8, SMPS power supply converts AC voltage to DC by rectifying and filtering the incoming AC voltage, then converting the DC to AC with a power switching controller DK1203 or equivalent, that allows high-speed transformer to steps down the voltage to desired level the represent for us the basic principle of SMPS.

The choice of an SMPS power supply is motivated by:

- SMPS power supplies are highly efficient compared to linear power supplies. it helps to minimize power loss and reduce consumption, which is important for long time working device such as the oxygen concentrator. **[7]**
- SMPS power supplies are generally smaller than linear power supplies. this compact size is an advantage in portable where space is limited. **[7]**
- Stability and reliability SMPS power supplies provide a regulated output power, ensuring stable and reliable power to the oxygen concentrator components. **[7]**

In our project we intend to design an SMPS with the following technical characteristics:

- **Input voltage range:** AC85V-265V
- **Output Voltage and current:** DC12V
- **Output current:** 1A
- **Switching frequency:** 65Khz

2.5. Control and display board diagram

The control and display panel of an oxygen concentrator enables users to operate the device by setting parameters like time, Bluetooth connectivity, and oximeter functions. it also displays error messages and alarms, providing users with essential information about the device. The diagram in Figure 2.9 represents the Control and display board for our oxygen concentrator control system.

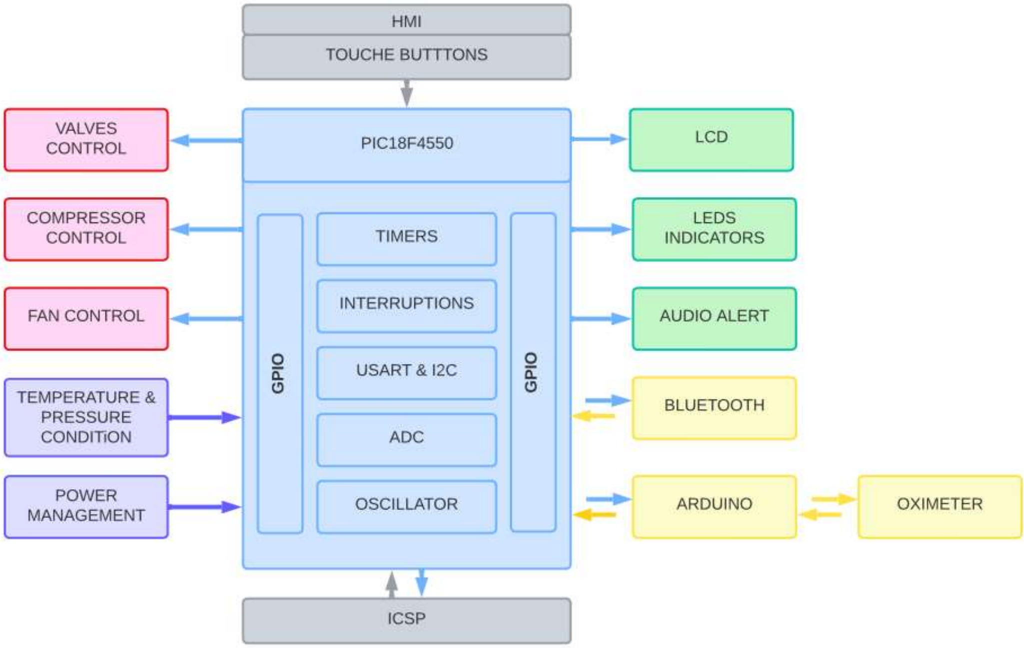


Figure 2.9: Control and display board bloc diagram.

2.5.1. Microcontroller unit (MCU)

Microcontrollers (MCUs) are programmable integrated circuits that include a microprocessor, memory and input/output peripherals on a single chip.

In this project, the PIC 18F4550 microcontroller was chosen because of its favorable system performance, low power consumption, large number of GPIOs, proven reliability and high availability. The Figure 2.10 represents PIC 18F4550 pinout

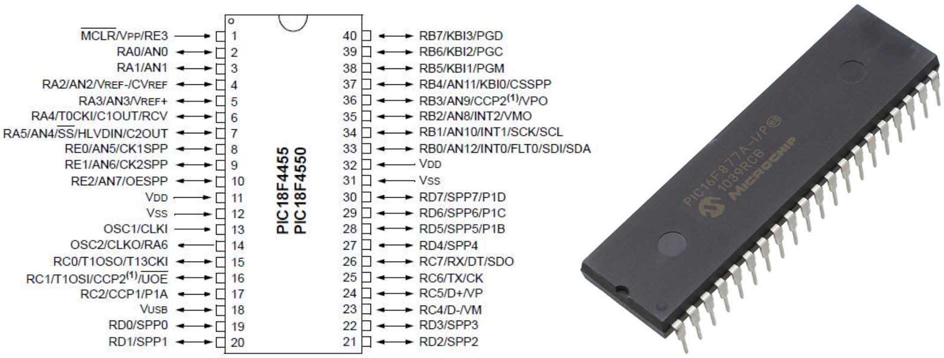


Figure 2.10: MICROCHIP PIC 18F4550 MCU.

To ensure the proper functioning of an oxygen concentrator, certain features are needed in the microcontroller unit (MCU). These include:

- Program Memory 32KB
- High Speed frequency clock up to 48 MHz
- Data EEPROM 256bytes
- 35 Pin GPIO
- Temperature range (-40/85)
- 13 ADC channel max ADC Resolution 10 bits
- Timers 1 x 8-bit - 3 x 16-bit
- 20 Interrupt Sources.
- Serial Communications (MSSP, Enhanced USART).

2.5.1.1. USART & I2C

USART The Universal Synchronous Asynchronous Receiver Transmitter (USART) module is a general-purpose serial I/O module that can be configured as a full-duplex asynchronous system for communication with devices such as terminals and computers. It also can be set up as a synchronous half-duplex system for communication with devices such as ICs and EEPROMs. The USART module allows bidirectional serial communication in both asynchronous and synchronous modes.**[8]**

The Master Synchronous Serial Port (MSSP) module in I2C (Inter-Integrated Circuit) mode is designed to perform both master and slave functions in an I2C communication system. It supports features such as general calling and provides hardware interrupts to detect start and stop bits, enabling multi-master operation on the bus. The MSSP module conforms to standard I2C mode specifications and supports both 7-bit and 10-bit addressing modes.**[8]**

2.5.1.2. Timers

PIC microcontrollers typically include built-in hardware timers that provide various timing and counting capabilities. These timers are essential for time-sensitive applications, event scheduling, and precise control of periodic tasks. figure 2.11 explaining timer1 functioning.

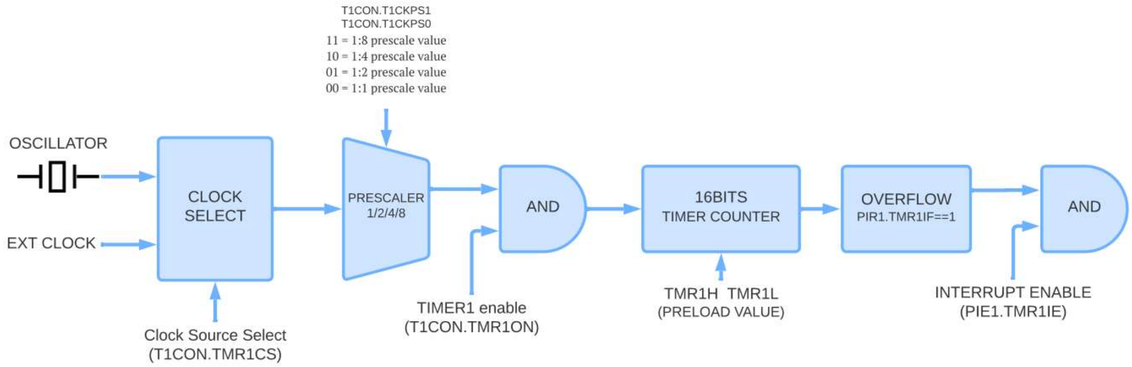


Figure 2.11: Timer1 block diagram.

In the PIC18F4550 microcontroller, the first step to calculate time is to select a clock source. The microcontroller offers two options: external and internal sources. The choice can be made by configuring the T1CON register's TMR1CS bit.

To calculate the time in seconds, a pre-scaler (PRD) is used to divide the frequency of 8MHz. The PIC18F4550 microcontroller provides pre-scaler options of 1, 2, 4, or 8, which can be set using the T1CON register's T1CKPS1 and T1CKPS0 bits.

The Timer1 module has a 16-bit timer (TMR1H and TMR1L) register It increments at a rate of (4 * PRD / fosc) seconds. When the 16-bit register overflows, an interrupt occurs. To achieve precise timing, a preload value (PRC) can be loaded into the 16-bit register.

The interrupt frequency (IF) represents the number of interrupts that occur in one second. To enable Timer1 in the PIC18F4550 microcontroller, we can use the T1CON.TMR1ON bit.

$$Interruption\ time = \frac{4*PRD*(2^{16}-PR\ )}{Fosc} second\ (\mathbf{1})$$

$$Interruption\ frequancy\ = \frac{1}{Interruption\ time}\ interruption/second\ \ (\mathbf{2})$$

2.5.1.3. Interruptions

Interrupts are a fundamental feature of microcontrollers, including PIC microcontrollers. They allow the microcontroller to respond to external events or internal conditions that require immediate attention, without relying on continuous polling. When an interrupt occurs, the microcontroller temporarily suspends its current execution and jumps to a predefined interrupt service routine (ISR) to handle the interrupt

In this project, we use two types of interrupts: timer1 and USART. Here is a short explanation of each of them:

Timer Interrupt: are activated based on the pre-defined parameters of a timer module in the microcontroller. When the timer reaches a desired value or overflows, it generates an interrupt, which allows the microcontroller to respond to the time event. Timer interrupts are commonly used for time-sensitive tasks, periodic tasks, or the generation of precise time ranges.

USART Interrupt: USART interrupts are used to handle events related to the transmission and reception of data. In this project, we use USART interrupts, which can be triggered when new data is received or when data transmission is completed.

2.5.1.4. ADC

The Analog-to-Digital (A/D) converter module that converts analog signals to a corresponding 10-bit digital number. It allows the microcontroller to interface with analog sensors such as pressure, temperature and battery level readings by sampling and quantizing the analog input voltage, providing digital data that can be processed and used for various applications**.[8]**

2.5.2. ICSP

(In-Circuit Serial Programming) is a feature of PIC MCU that allows programming and debugging of the microcontroller while it is still connected to the circuit. It uses special pins to communicate with a programmer/debugger, allowing for real-time updates of firmware and debugging without removing the microcontroller from the circuit**.[8]**

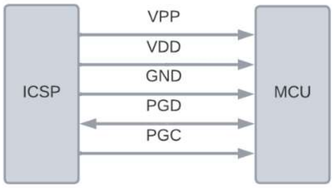


Figure 2.12: In-Circuit Serial Programming.

2.5.3. Human Machine Interface

In the oxygen concentrator project, there are four buttons to control the device. The "On" and "Off" buttons are used to start or stop the device. And two buttons to increase or decrease time. When the time remaining is less than one hour, pressing the button increases the time by 10 minutes. If the remaining time is more than one hour, pressing the button increases the time by half an hour.

In addition to the previous buttons, there is an additional button to reset the device in case of problems. Another feature is that by holding down the "On/Off" button for an extended period of time, the LCD display will reveal hidden parameters such as activating the Bluetooth and oximeter functions, as well as resetting the total time to zero the total time it uses to change the zeolite molecular.

2.5.4. Power management

In the power management system, when power is interrupted, the microcontroller detects the absence of AC line input and activates the appropriate response. It stops all running applications, activates a flashing light indicator, and sounds an alarm to indicate a power failure or problem. There is a 9v battery backup to supply the alarm system.

2.5.5. Temperature & pressure sensors

In this setup, temperature and pressure sensors are used to detect the temperature and pressure of the compressor. They provide real-time feedback on the status of the compressor, which allows the compressor operating parameters to be controlled in the case of an increase in the pressure of the heat.

2.5.5.1. Temperature

In this setup shown in figure 2.13, an NTC (Negative Temperature Coefficient) thermistor is used to measure compressor temperature. is a type of temperature sensor that decreases in resistance as the temperature increases. Through measuring the resistance of the NTC, the temperature can be measured.

In our configuration, we use a 10k Ohm NTC thermistor, which has a resistance of 10k Ohm at room temperature. By embedding a voltage divider circuit with an additional 10k Ohm resistor, we can determine the current passing through the two resistors in series. we measuring the voltage across the NTC thermistor using the MCU, we can calculate its value.

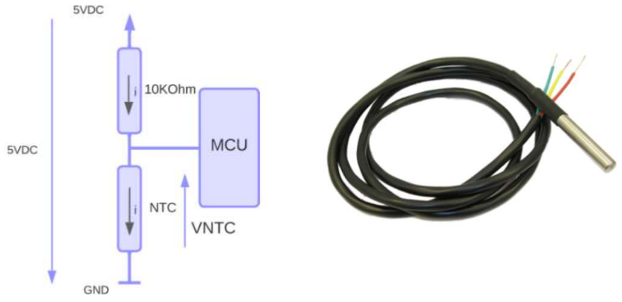


Figure 2.13: NTC temperature sensor**.**

In our configuration, we use a 10k Ohm NTC thermistor, which has a resistance of 10k Ohm at room temperature (25C°). By adding a voltage divider circuit with an additional 10k Ohm resistor, we can determine the current (i) flowing through the two series resistors. The MCU uses the ADC and calculates the value of the voltage (VNTC). The next step is to convert it to temperature using the Steinhart equation.

$$\frac{1}{T}=\frac{1}{T0}+\frac{1}{B}*ln\,(\frac{R}{R0})\ \mathbf{(3)}$$

T = temperature measured in Kalvin.
T0 = room temperature in Kalvin.
B = the coefficient of the thermistor usually from 3950 to 4050.
R0 = NTC resistance (10k Ohm) in room temperature.
R = the measured resistance.

2.5.5.2. Pressure

XGZP6847A is a model of pressure sensor. Use in the medical field and health equipment, various devices are used for different purposes oxygen concentrators. These include blood pressure tests and monitors, patient monitoring systems, infusion and syringe pumps, anesthesia machines this some of features.**[9]**

- Ranges: -100kPa～0kPa…1500kPa
- Optional 5V or 3.3V or 3V power supply
- Gage & Vacuum Type
- Calibrated Amplified Analog signal or Digital output
- Temp. Compensated:0℃～+60 ℃

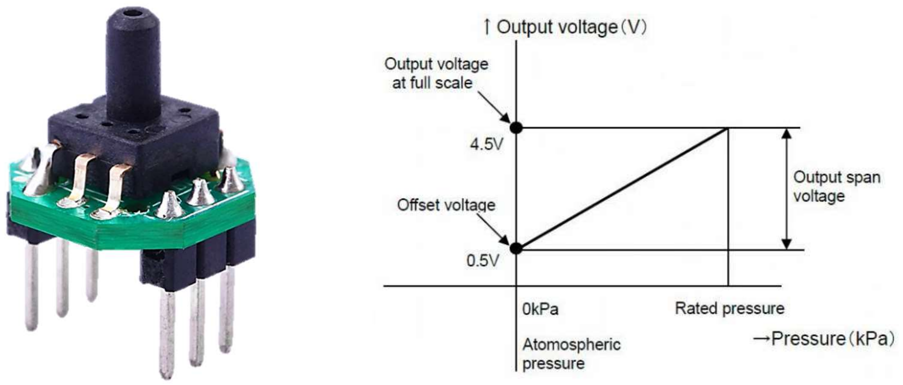


Figure 2.14: Pressure sensor.**[9]**

Equation for calculating pressure from the numerical value read

$$P = \frac{output - 0.5}{K} \quad \textbf{(4)}$$

K Factor = 0.02.
Output = read digital value from MCU.
P= the measured pressure.

2.6. Auxiliary board (oximeter)

2.6.1. Oximeter (MAX30102)

The MAX30102 module is a compact, integrated design for pulse oximetry and heart rate measurement. It integrates LEDs, photodetectors, optical components and low-noise electronics with ambient light rejection. This module is designed to simplify the integration process for mobile and portable devices, offering a complete system solution the Figure 2.15showing use max30102 pinout.**[10]**

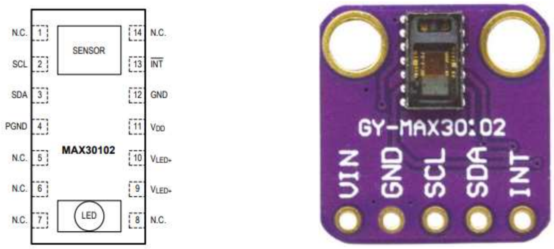


Figure 2.15: MAX30102 Module. **[10]**

2.6.2. Interfacing the sensor with the secondary MCU

To calculate SpO2 and HR using Arduino, use a special library for practical purposes. Connect the sensor to Arduino as shows in figure 2.16, using I2C, connecting the power and ground pins, as well as the SDA and SCL pins between the sensor and Arduino. In addition, an interrupt pin is used to manage events from the sensor. The pin is connected between the sensor and the Arduino, allowing the Arduino to reply instantly to events detected by the sensor.

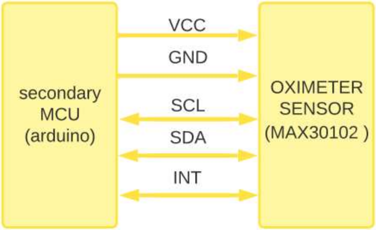


Figure 2.16: Interfacing MAX30102 Module with Arduino.

2.7. Bluetooth connectivity

We used the HC-05 as shows in figure 2.17 below a Bluetooth Serial Port Protocol (SPP) module for wireless serial communication. It is Bluetooth V2.0+ EDR (Enhanced Data Rate) rated up to 3Mbps and is equipped with a 2.4 GHz radio transceiver and baseband for reliable connectivity. **[11]**

HC-05 features:

- Typical -80dBm sensitivity
- Up to +4dBm RF transmit power
- Low Power 1.8V Operation ,1.8 to 3.6V I/O
- UART interface with programmable baud rate
- With integrated antenna
- With edge connector

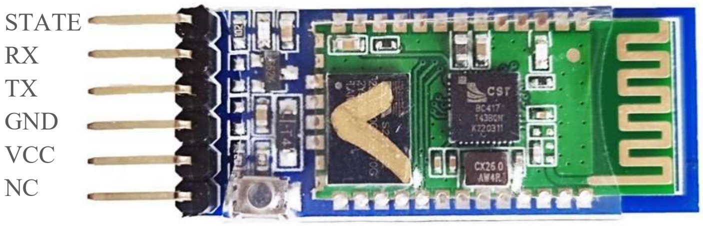


Figure 2.17: HC-05 Bluetooth module pinout. **[11]**

The device is used to control the unit wirelessly and set the operating time, as well as displaying oxygen concentrator parameters such as pressure and temperature, and displaying blood saturation and heart rate using a smartphone app.

The figure 2.18 below shows the Bluetooth module interfacing with the pic microcontroller, the power supply with the VCC and GND pins, the transmitter and receiver pins to ensure communication between them, the enable pin to activate or deactivate the module and the last pin to show the use of acknowledgement if a smartphone is connected with the device.

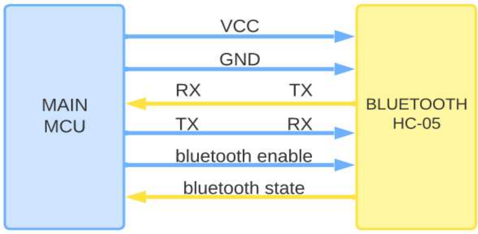


Figure 2.18: Interfacing Bluetooth Module with main MCU.

2.8. Conclusion

In this chapter, we discuss the essential components involved in controlling a portable oxygen concentrator (POC). These include essential components such as the power supply, communication interfaces (UART, I2C), sensor integration, user interface features (buttons, display).

In the next chapter, we'll look at the results of our work and discuss the algorithms we've used to make the portable oxygen concentrator (POC) work. This will involve analyzing the device's performance, evaluating the accuracy of the measurements and the effectiveness of the algorithms in delivering the desired oxygen concentration to the user.

CHAPTER III:

SIMULATION RESULTS AND PRACTICAL DESIGN

3.1. Introduction

In this chapter, we present our control algorithms that will be implemented on the designed control board. In addition, we will show simulation and practical realization results of our POC control board and power supply board.

3.2. Software environment

In this section, we describe the software environment used in the various stages of the design of this project.

3.2.1. MikroC PRO FOR PIC

To program the PIC 18F4550 microcontroller, we used the MikroC PRO C language compiler for PIC. This full-featured compiler from mikroelektronika offers an easy-to-use IDE, powerful optimizations and a host of ready-to-use examples. It is an ideal solution for developing code for PIC devices, enabling us to work effectively.

3.2.2. Labcenter Proteus

Proteus, developed by Labcenter Electronics, is a complete software suite for the design and simulation of complete electronic systems, including microcontroller code. It is made up of two main software packages: ISIS (Intelligent Schematic Input System) widely recognized for its schematic editing capabilities and ARES, a placement and routing tool. Proteus is a powerful tool for electronic circuit design and simulation, facilitating the development of efficient and accurate systems.

3.3. Power consumption estimation

To ensure sufficient power supply for our circuit, we need to match the power consumption values of the main components, as shown in Table 3.1.

Components	Current	Voltage
Arduino	200mA	05VDC
LCD	170 mA	05VDC
PIC18F4550	100mA	05VDC
Fan	100mA	12VDC
Valve	80 mA	12VDC
Bluetooth	80mA	05VDC
Pc817C *4	80mA	05VDC
Buzzer	32mA	05VDC
Buzzer	15mA	12VDC
LEDs*3	18 mA	05-12 VDC

Table 3.1: the main components power consumption.

From the power consumption report in Table 3.1, the total current consumption of our circuits is approximately 950 mA. So, we need two voltage sources 12V and 5V to meet our power requirements.

This justifies the choice of an SMPS instead of a linear power supply. SMPSs are more efficient, smaller and better regulated than linear power supplies.

3.4. Power supply board circuit

3.4.1. SMPS Circuit diagram

Figure 3.1 shows our SMPS circuit diagram used to provide a stable 12VDC output from a 220VAC power source.

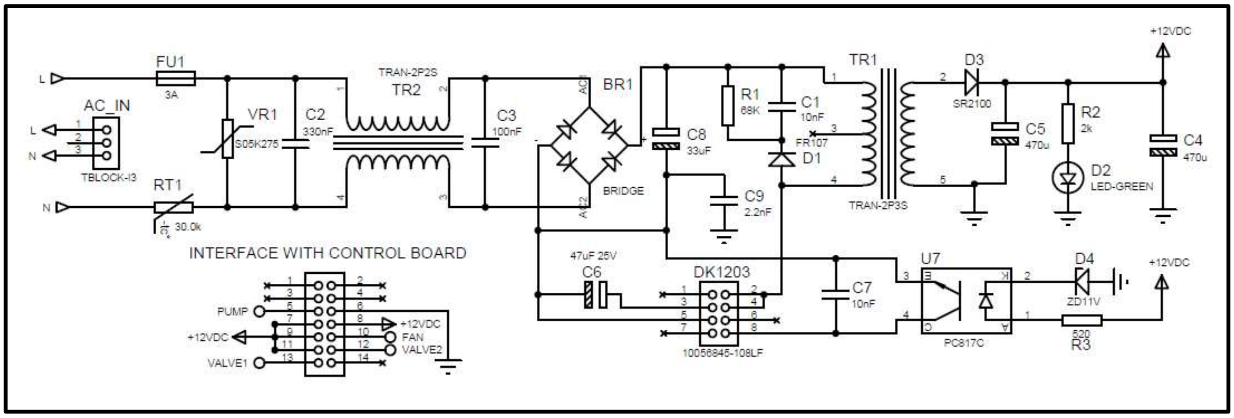


Figure 3.1: 12VDC SMPS Circuit diagram.

This SMPS circuit diagram offers protection against overcurrent, overvoltage and inrush current using the following components:

- A 3A fuse (FU1) to provide protection against overcurrent.
- A 275VAC MOV (VR1) or Metal oxide Varistors which is a high value resistance under normal operation but acts as a short circuit when voltage is above 275VAC, to protect the circuit against overvoltage. **[7]**
- The NTC(RT1) provides protection against inrush current (high resistance in case current is above limits during power up).

An EMI filter (C2, TR2 and C3) is also used to reduce electromagnetic interference where TR2 is a choke coil inductor to avoid voltage spikes.**[7]**

From this circuit diagram we notice that input AC voltage is rectified to DC using Full wave rectifier bridge (BR1) and a smoothing filter which consists of a bulk capacitor (C8).

Next, a step-down transformer (TR1) is used to reduce voltage to about 12VAC and a PWM switching controller (DK1203) is used to convert DC to AC. Finally, a Diode (D3) and capacitor(C5) are used to obtain 12VDC (output rectifier).

To keep the output stable, a feedback loop provides feedback to the switching controller (DK1203) to regulate the output voltage to 12VAC.

The feedback loop of our SMPS circuit consists of an 11V Zener D4 diode and an optocoupler U7 with a forward voltage of 1.2V. This combination establishes a reference voltage of 12.2V. When the output voltage exceeds 12.2V, the Zener diode blocks the AC voltage, which keeps it stable and regulated. **[7]**

The 14-pin connection is used to provide 12 VDC for the control and display board and get the order to control the valves, fan and compressor at the same time from the MCU in control and display board.

3.4.2. Fan and valves circuit diagram

As both valves and FAN in the targeted POC needs to operate in 12VDC, we included their control circuitry within the power supply board. Figure 3.2 shows the valves and FAN control circuit diagram.

As the valves are rated 12V 1W we used a classical PNP switch circuit to control them, however, as the FAN needs more important current to operate properly, we used the MOSFET IRFZ44N instead it can handle a continuous current flow of up to 49A.

To protect the circuit against reverse current discharge, we used freewheel diodes (D6, D7and D9) in parallel to valves and fan coils and another protection diode (D8) in series with the control signal pin to avoid reverse voltage discharges to the main MCU.

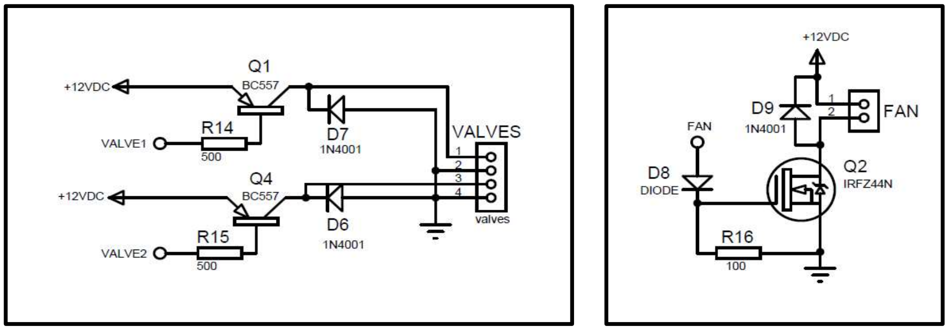


Figure 3.2: 12VDC Fan & valves control circuit diagram.

3.4.3. Pump circuit diagram

As the pump is operated in 220VAC, its control circuit was included too within the power supply board. The figure 3.3 shows the circuit diagram of the pump.

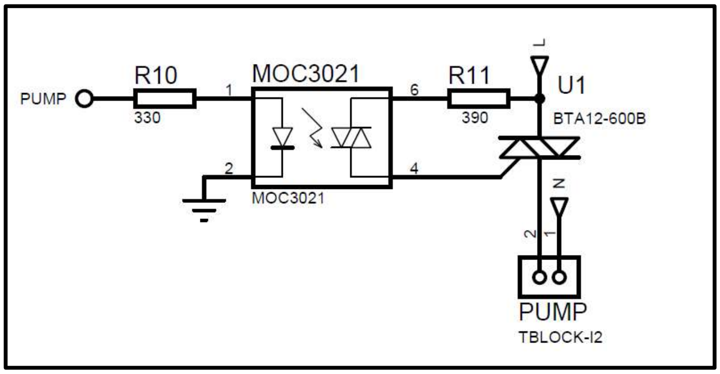


Figure 3.3: 220VAC Pump control circuit diagram.

The BT12-600B TRIAC operates as an AC switch to power the Compressor pump by providing the necessary 220VAC. The MOC3021 is an optotriac that provides electrical isolation between the PIC microcontroller and the high-voltage circuit components. This isolation ensures that the PIC is protected from potential electrical risk.

3.5. Control & display board

3.5.1. Main MCU circuit diagram

This Figure 3.4 shows all the different input and outputs to the main MCU PIC18F4550.

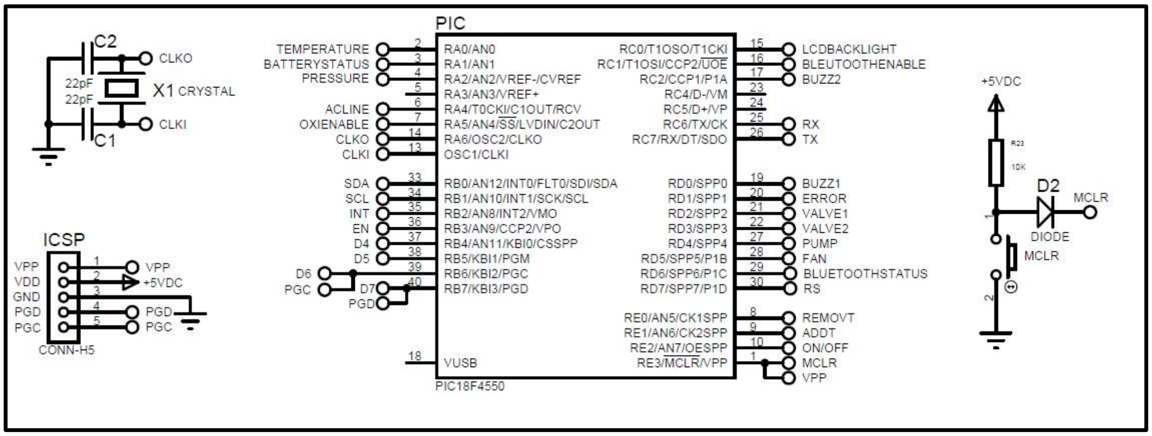


Figure 3.4: Main MCU circuit diagram.

The MCU is clocked at 8Mhz and with ICSP implemented to program and debug the MCU directly on board.

The MCLR button is used to reset the MCU by triggering a reset signal when pressed, enabling troubleshooting or initialization.

3.5.2. HMI circuit diagram

Figure 3.5 shows the HMI block diagram that includes three pushbuttons and an (LCD).

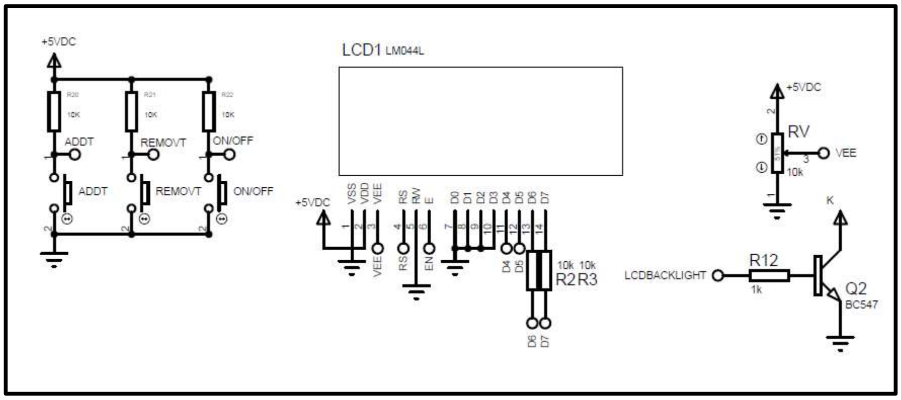


Figure 3.5: HMI circuit diagram.

- The push-buttons allow the user to control the different options of the device, turn ON/OFF and set the compressor ON Time.
- The LCD screen (20*4) is used to display various information to the user.
- The RV and BC547 transistor used to control LCD brightness and backlight.

3.5.3. Pressure & temperature sensors interface

Figure 3.6 shows the interface circuits diagram.

For the temperature sensor we use an NTC of 10K Ohm at room temperature and for the pressure sensor we use the XGZP6847A module. Both components operate at 5VDC.

The Zener diode D4 and capacitor C3 are inserted for voltage protection and voltage stability.

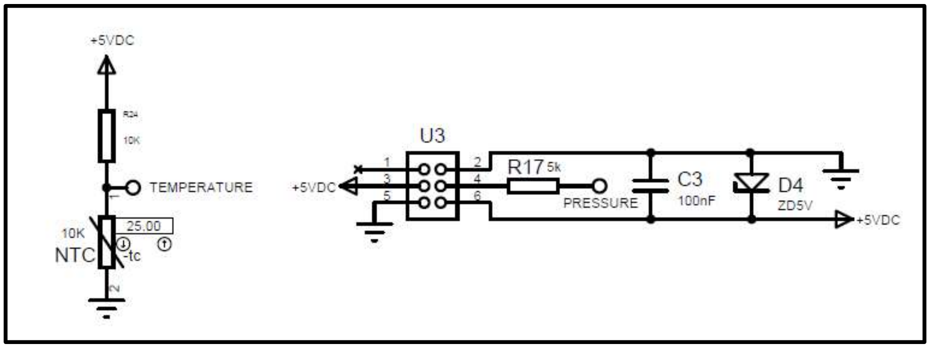


Figure 3.6: Pressure & temperature sensors interface.

3.5.4. Alarms system circuit

Figure 3.7 shows an alarm system with two buzzers and a flashing error LED, all controlled by the microcontroller (MCU).

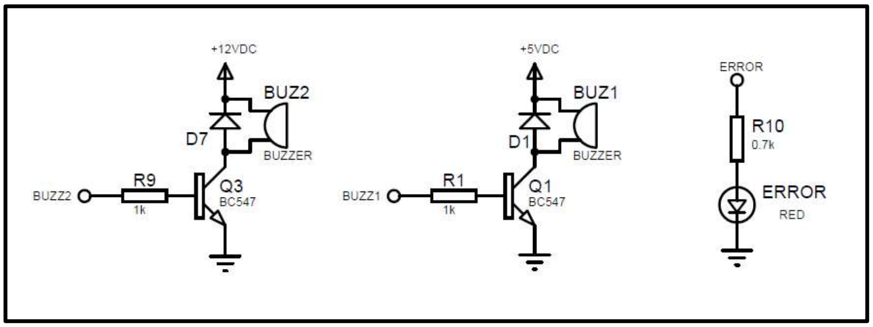


Figure 3.7: Alarms system circuit diagram.

Transistor BC457 is used to activate the buzzers when an HMI button is pressed or a fault detected, while the LED flashes to indicate the occurrence of an error or power outage.

3.5.5. Bluetooth interface

Figure 3.8 shows the interface to connect the main MCU with the Bluetooth module.

This circuit shows a transistor that acts as a switch, controlled by the PIC MCU using the BLUETOOTHENABLE pin, to enable or disable the Bluetooth module if needed.

Communication between the PIC MCU and the Bluetooth module is via the USART protocol, enabling communication between the MCU and a smartphone application using Bluetooth.

The Bluetooth status pin can indicate whether a device is currently connected to the device.

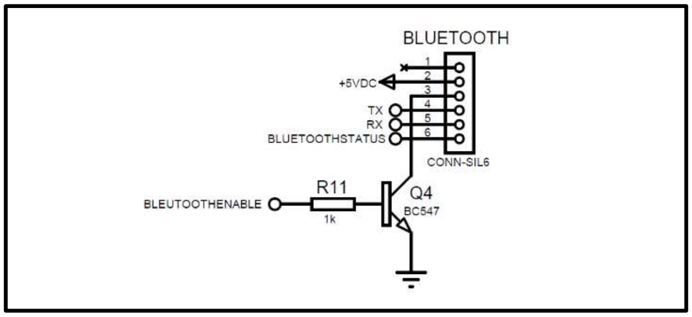


Figure 3.8: Bluetooth interface circuit diagram.

3.5.6. Power monitor & backup circuit diagram

We need to convert in the control board the 12VDC coming from the power supply board so we can power all the interfaces that operate in 5VDC.

Figure 3.9 shows a circuit diagram to produce a constant 5 VDC on the control board from the 12 VDC output of the power supply board using the LM7805 voltage regulator. Input and output capacitors (C4 and C5) are used to ensure voltage stability.

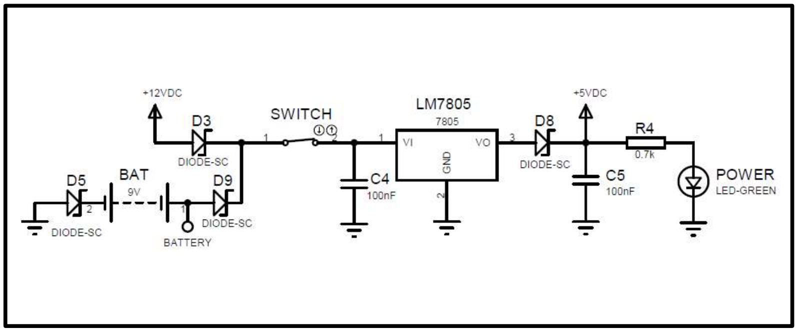


Figure 3.9: Control board 5VDC source circuit diagram.

In addition, a backup battery (BAT) is connected to the 12 VDC input to serve as a power source in the case of a power outage. In this case, a diode(D9) is used to draw current from the battery, ensuring a continuous 5VDC supply. The diode (D5) provides protection if the battery is connected in the reverse direction.

Figure 3.10 shows a 5VDC backup power supply circuit diagram that ensure continuous operation of the control board in case of power outage.

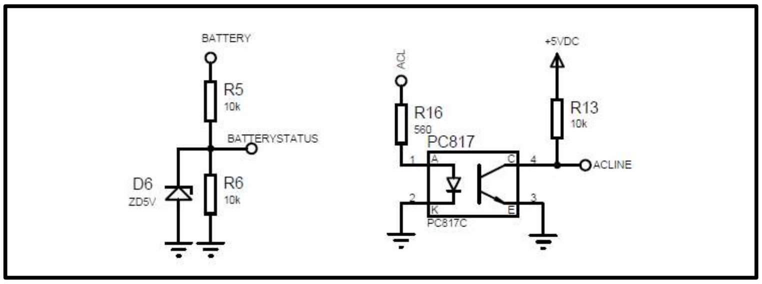


Figure 3.10: 5VDC Power backup circuit diagram.

On the right side, the system detects the presence of the AC power line. If the power line fails, the MCU interrupts operation and activates an audible alarm to warn of power loss.

On the left side, a voltage divider is used to allow the MCU to check the battery level using an analog port. When the battery level is too low, a notification is displayed on the LCD screen to warn about the need to replace the battery packs.

We used an optocoupler to ensure isolation between our MCU and the 12VDC line.

3.6. Auxiliary board interface

Figure 3.11 shows the oximetry system configuration used as an auxiliary board connected with the main control board.

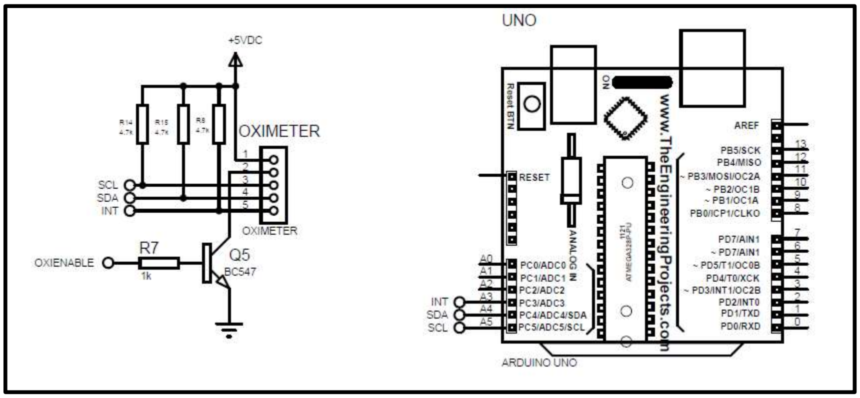


Figure 3.11: Oximeter auxiliary board interface.

The oximeter sensor is connected to the Arduino microcontroller using the I2C protocol. To control the oximeter, the main control board MCU (PIC18F4550) uses a transistor as a switch, allowing the oximeter to be activated or deactivated. This allows the Arduino to read the data from the oximeter sensor and provide perform the necessary information.

Finally, the sensor uses an interrupt pin to inform the Arduino when the sensor buffer is filled with data. This enables the Arduino to handle the data quickly and take the required action.

3.7. Implemented control algorithms

In this section, we'll explain the different algorithms of the main routines implemented into the main MCU to make our control & display board work properly to drive the targeted POC and supply oxygen at the output.

3.7.1. Main Algorithm

Figure 3.12 shows the flowchart of the main algorithm used in our project.

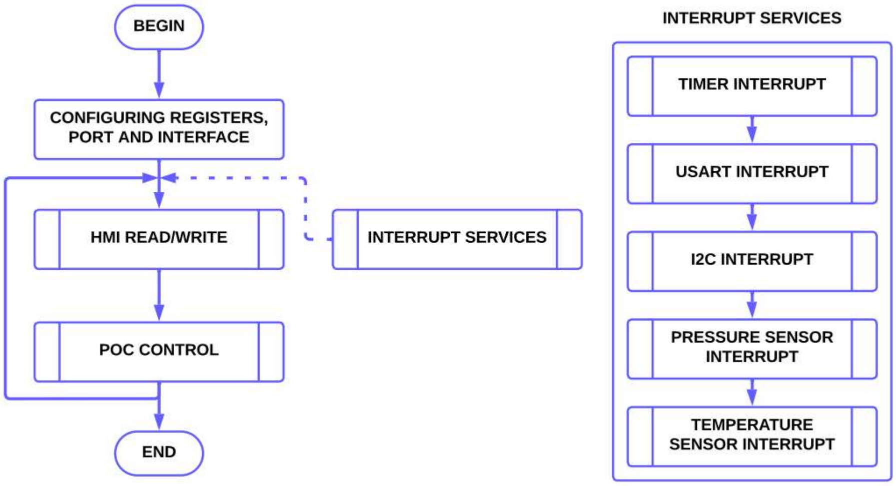


Figure 3.12: Main algorithm flowchart.

We need first to configure ports and registers of the main MCU PIC to prepare its input/output interfaces to work properly by configuring their corresponding registers.

This include oscillator**,** I/O ports, ADC ports and any special features of the MCU such as pullup resistances, Timers, interrupts, UART, I2C... etc...

Our main algorithm can be divided into multiple subroutines:

- Sensors input subroutine
- POC Control subroutine
- HMI read/write subroutine
- Interrupts services routines

3.7.2. Sensors input subroutine

The device includes three analog sensors (battery level, temperature and pressure) used to control its components, and a digital sensor to detect AC power outages.

- The battery status measurement provides information on the battery's charge level.
- Temperature measurement monitors the temperature of the surrounding environment of the compressor.
- Pressure measurement provides oxygen tank pressure levels.
- The AC line sensor detects the presence in the power line.

Figure 3.13 shows the flowchart on how to read these sensors input.

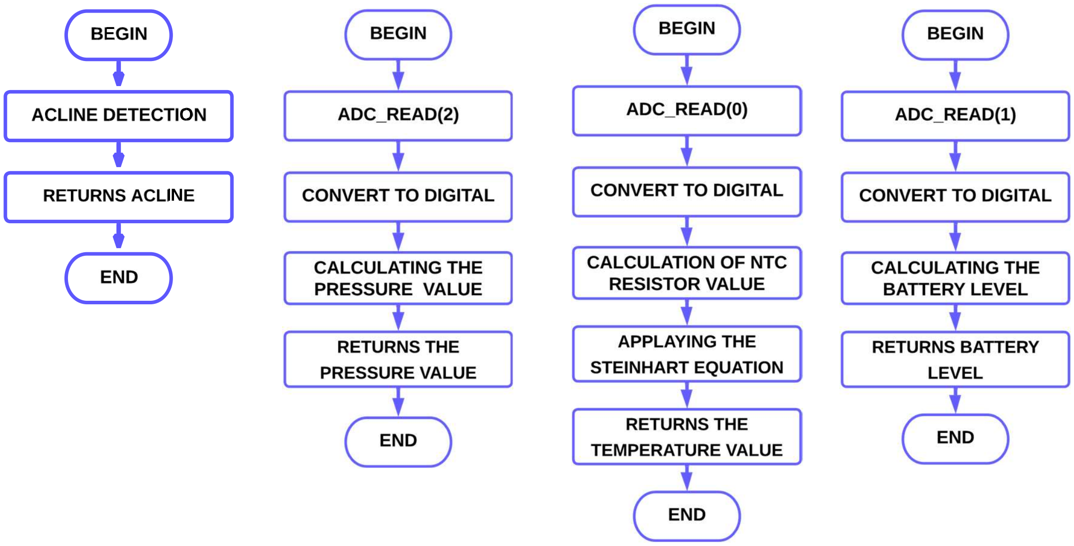


Figure 3.13: Sensors reading flowchart.

3.7.3. HMI Read/Write subroutines

The HMI flow chart enables the user to set the time, start or stop the device using buttons or the application, and view parameters such as total time, pressure, temperature, oxygen saturation, and heart rate. Figure 3.14 shows HMI flowchart.

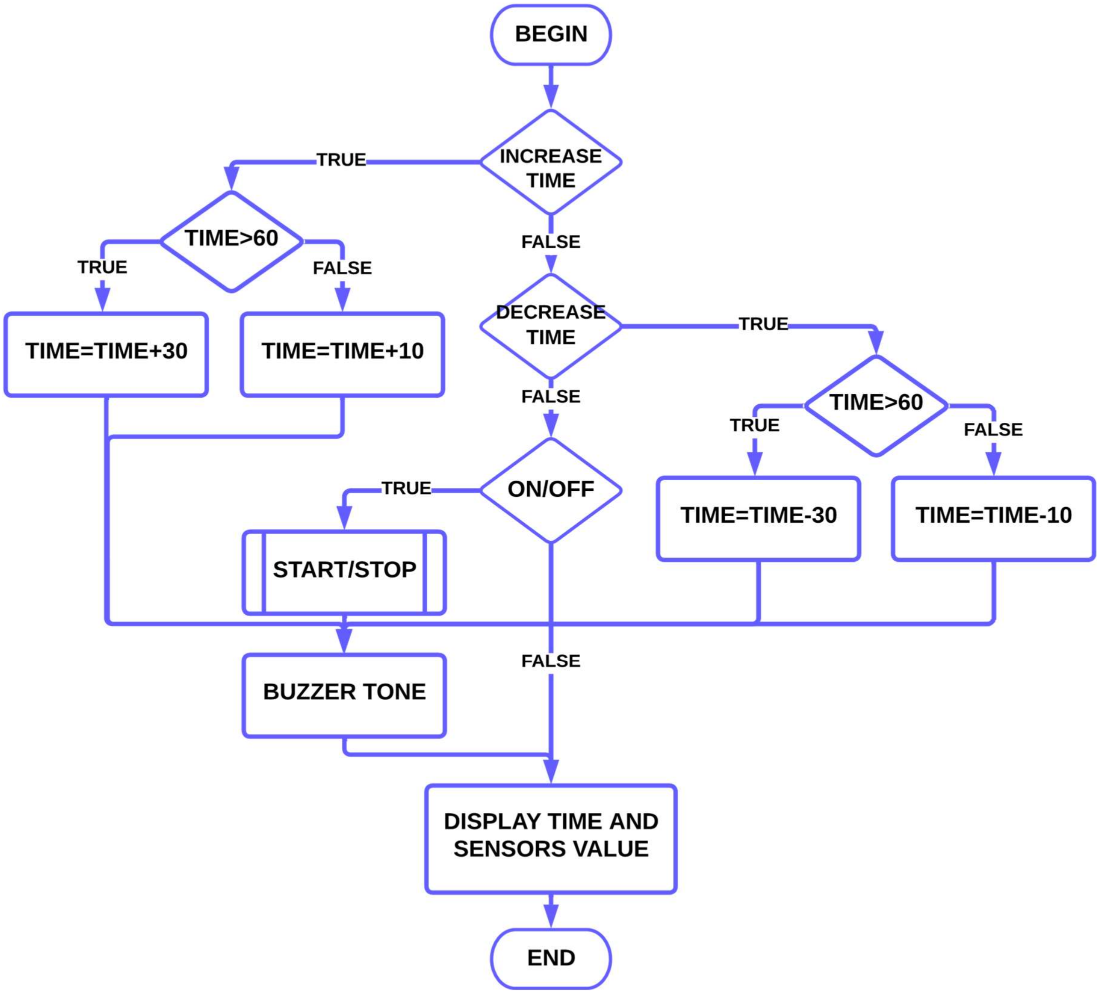


Figure 3.14: HMI Read/Write routines flowchart.

The timer value depends on the user input via the HMI interface two buttons: "Add" and "Remove" and the timer is managed using a timing algorithm shown in figure 3.14.

In this flowchart, we notice that:

- If the "Add" button is pressed, the time will be increased by 10 minutes. If the current time is less than one hour.
- Otherwise, if the time is greater than one hour, it will increase by half an hour.
- In the same way, when you press the " Remove " button, the time decreases by 10 minutes if the current time is less than one hour.
- If the current time is greater than or equal to one hour, pressing the " Remove " button will decrease the time by one hour.
- The on/off button allows users to start or stop the POC system with a single press, while a long press gives access to the settings menu.

The time entered is saved for later use. It is stored in memory and the device wait the user to start the device or resetting the time. In this step, each digit of the time will be converted into a character for display on the lcd screen.

3.7.4. POC control subroutine

The POC control subroutine is the most important subroutine in this project as it implements the PSA principle to control the compressor and the two valves in a timely manner to provide sufficient pure oxygen at the output of the targeted POC shown in Figure 3.15.

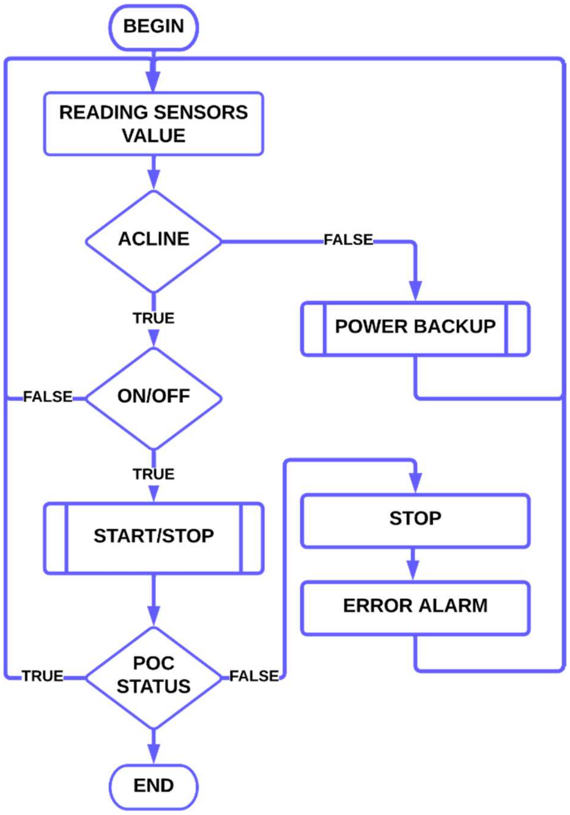


Figure 3.15: POC control flowchart.

We control the start & stop of the pump according to the PSA principle by:

- Continuously reading sensors status
- Check If user starts the compressor with the ON/OFF button.
- To start the compressor, we sense AC line first
- If AC Line not present (power failure), we engage urgent actions (stop / alarm)
- If AC line is present, we start the compressor
- Continuously checking POC general conditions
- If conditions normal, continue to operate, otherwise engage urgent security actions

Failing to respect timing or security measures will cause irreversible damages to the POC hydraulic and pneumatic circuit.

3.7.5. POC status subroutine

The figure 3.16 shows POC status flowchart

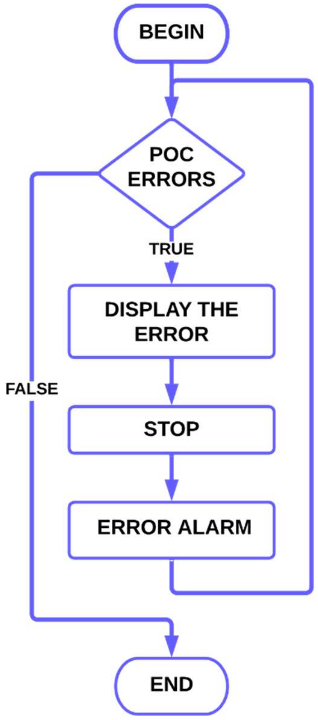


Figure 3.16: Device conditions subroutine flowchart.

When the POC is stopped, all the component are set to zero that mean the timer1 is stopped the pump fan and the valves are stopped also.

Compressor can be stopped by the user or any external event such as overpressure, overheat, or under pressure errors. Figure 3.16 shows the POC status subroutine steps required to detect any overheating, overpressure and under pressure conditions in the compressor.

Compressor temperature and pressure are continuously monitored. If overheating, overpressure or under pressure is detected, the device is stopped and release an alarm and display the problem through LCD screen.

3.7.6. Start stop subroutine

The Figure 3.17 shows in more details the compressor start/stop subroutine flowchart. When the start stop button is pressed:

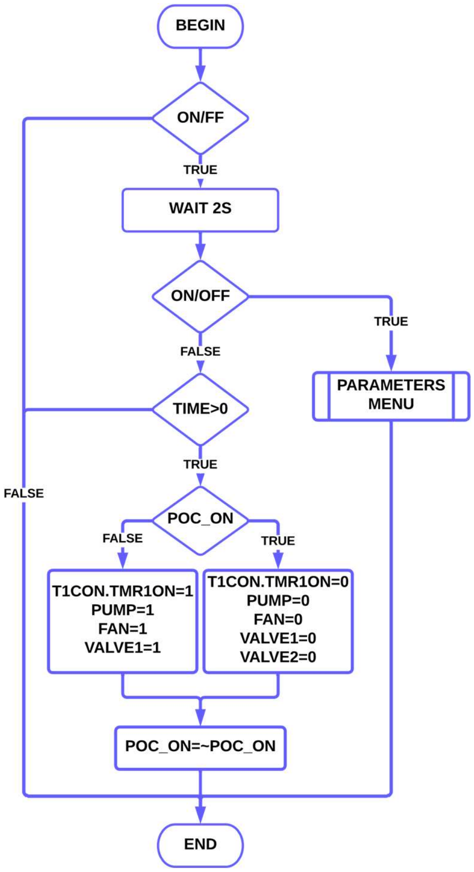


Figure 3.17: START&STOP flowchart.

- POC starts or stops depending on its current status (normal, overpressure, overheat …etc.);
- If the button is pressed for a period of time, the MENU PARAMETERS is displayed.

3.7.7. Menu parameters subroutine

- The MENU PARAMETERS is displayed in the LCD of the HMI when holding down the on/off button for two seconds.
- This menu allows you to enable Bluetooth (Bluetooth EN), auxiliary oximeter (Oximeter EN) or reset the total running time of the device as shown in figure 3.18.

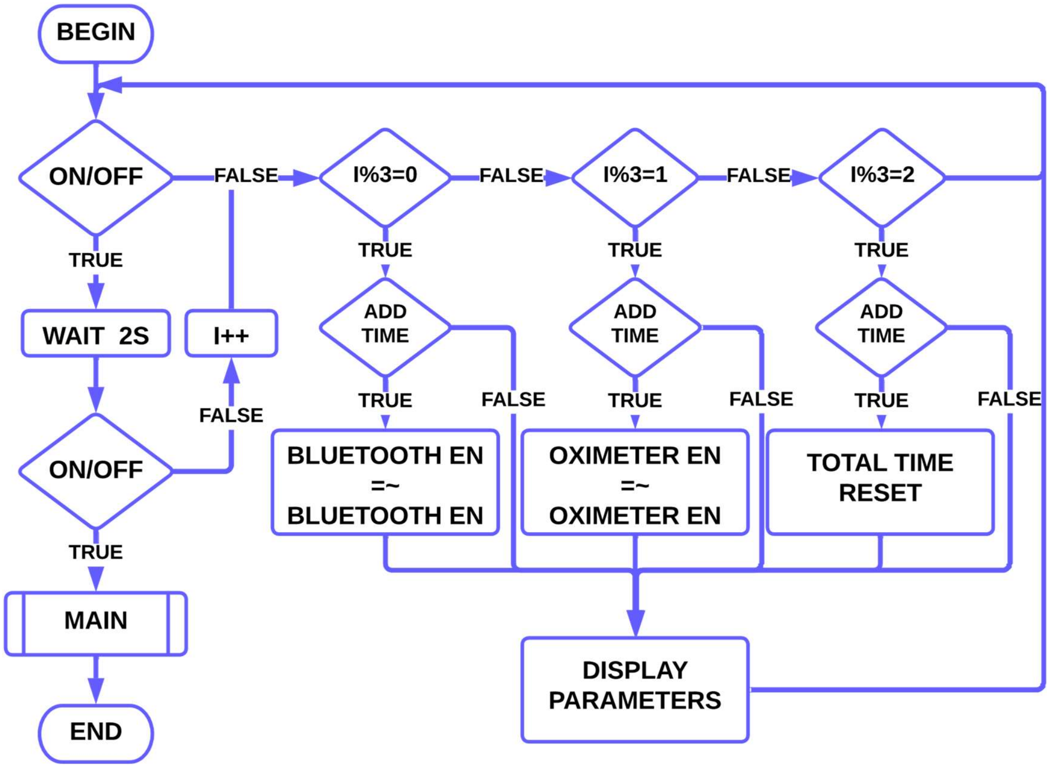


Figure 3.18: Menu parameters flowchart.

3.7.8. Power backup subroutine

In the case of a power loss, an alarm buzzer and a flashing LED used to warn users. The buzzer provides an audio signal, while the flashing LED provides a visual sign of power loss. In addition, shutting down other functions saves energy as shown in figure 3.19.

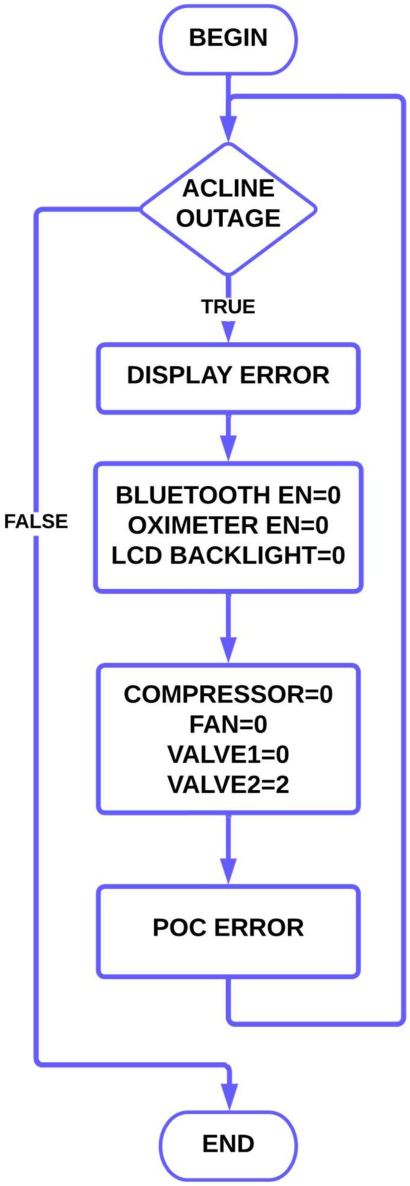


Figure 3.19: Power backup subroutine flowchart

3.7.9. Bluetooth management subroutine

In figure 3.20 we show data sending flowchart, we intend to send POC device status such as oxygen concentrator status, compressor temperature and pressure, heart rate and oxygen saturation through the Bluetooth module to the phone application.

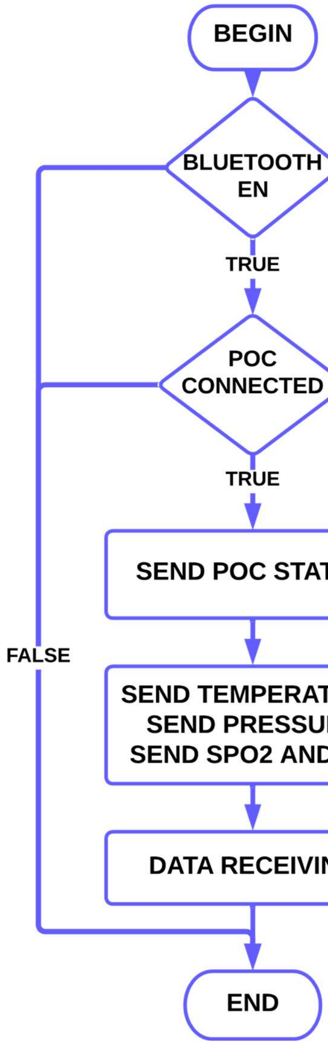


Figure 3.20: Bluetooth management flowchart.

3.7.10. Interrupts services routines

The PIR register in PIC microcontrollers is divided into two-byte registers, PIR1 and PIR2. PIR1 contains flag bits for specific interrupts like (PIR1.TMR1IF) Timer 1 Interrupt Flag bit and (PIR1.RCIF), UART Receive, and (PIR1.SSPIF) it Master Synchronous Serial Port Interrupt Flag bit

According to figure 3.21, we have three different interrupts subroutines in our algorithm which are:

- Timer1 interrupt to handle the timing functions used in this project.
- UART interrupt to handle the Bluetooth connectivity.
- I2C interrupt to handle the main MCU PIC communication with an auxiliary board such as the Oximeter board (Arduino based).

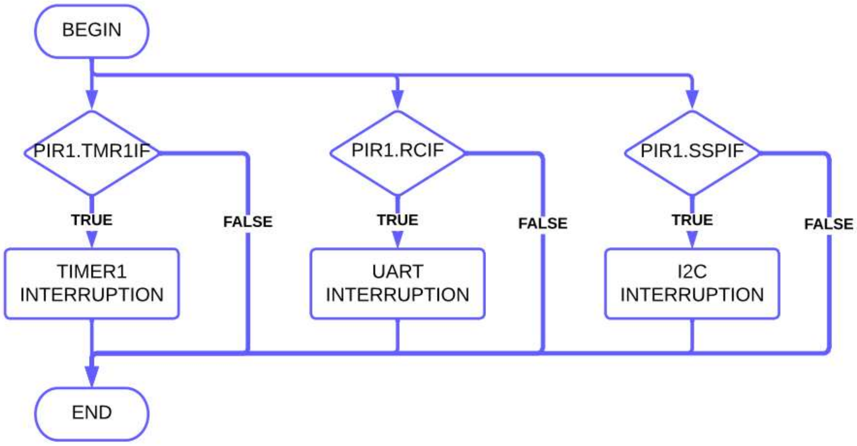


Figure 3.21: Interruptions services routines flowchart.

3.8. Simulation results

A simulation was performed to test and validate the program's operation and verify the accuracy of the previous steps.

These simulations are a fundamental step in ensuring the success of the project's practical implementation.

Once all the board components have been successfully wired to the Porteus software and the Hex file created by the MikroC software has been uploaded to the PIC microcontroller, the simulation of the circuit can start.

Figure 2.22 shows the interface for starting up our circuit, indicating that the simulation process is ready to begin.

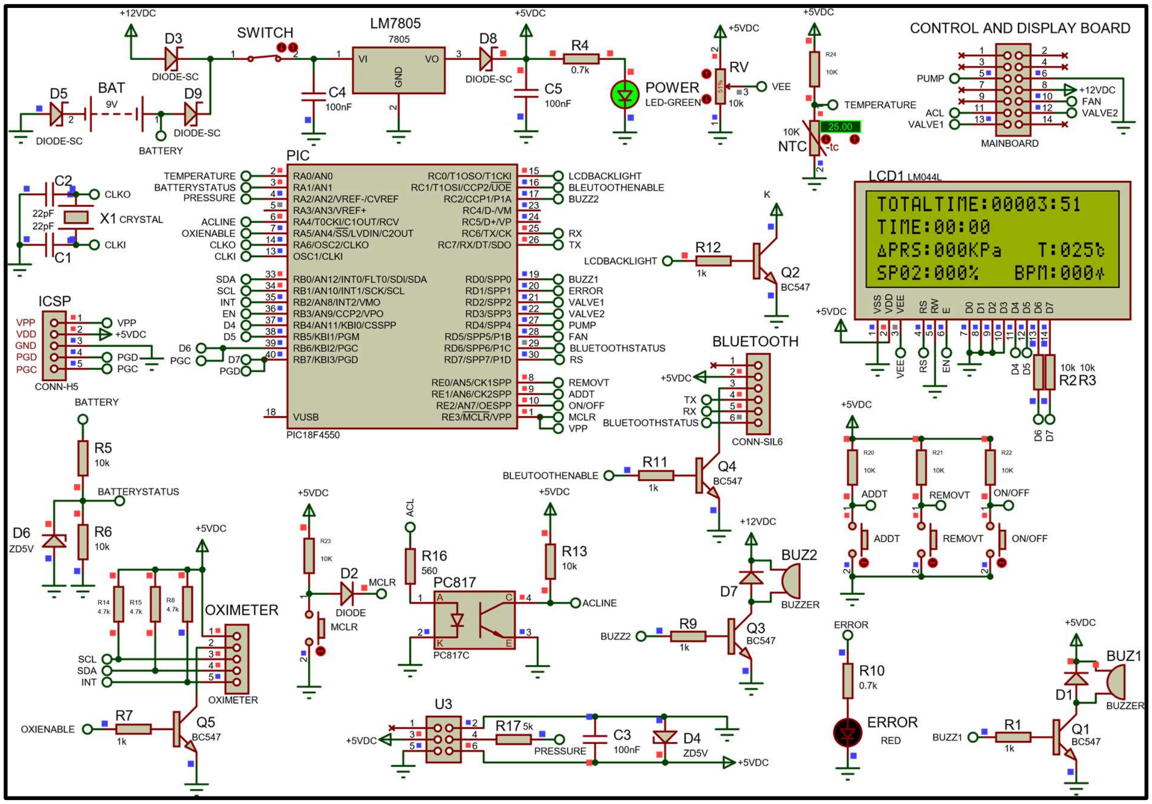


Figure 3.22: Control and display circuit simulation.

3.8.1. Interface

Figure 3.23 shows the HMI circuit, where the LCD screen displays important information such as total device runtime, user-entered time, compressor pressure and temperature, in addition saturation and heart rate values.

In this particular case, the device is switched off, as shown by the output of microcontroller unit in low-level

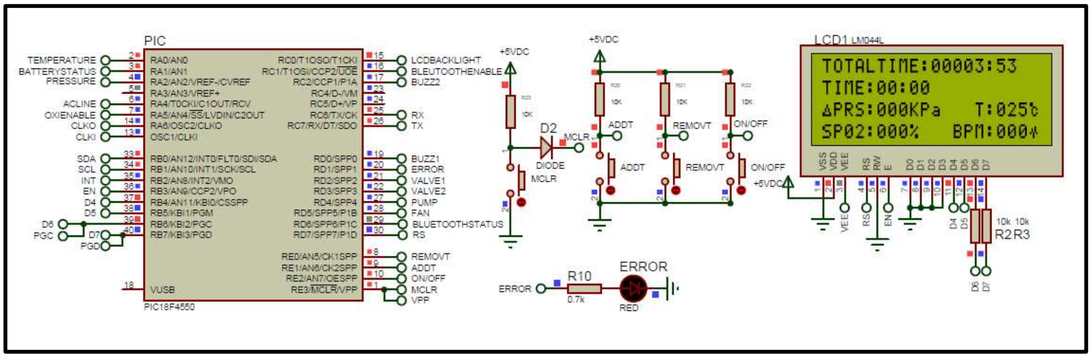


Figure 3.23: HMI circuit simulation.

Figure 3.24 shows the device in operation. The LCD display shows the 40-minute time entered by the user, indicating the desired running time. Compressor pressure and temperature are displayed in normal conditions, ensuring correct operation. Both compressor and fan are switched on. In addition, valve 2 is open, while the other valve is closed the clock symbol to indicate that the device is switched on.

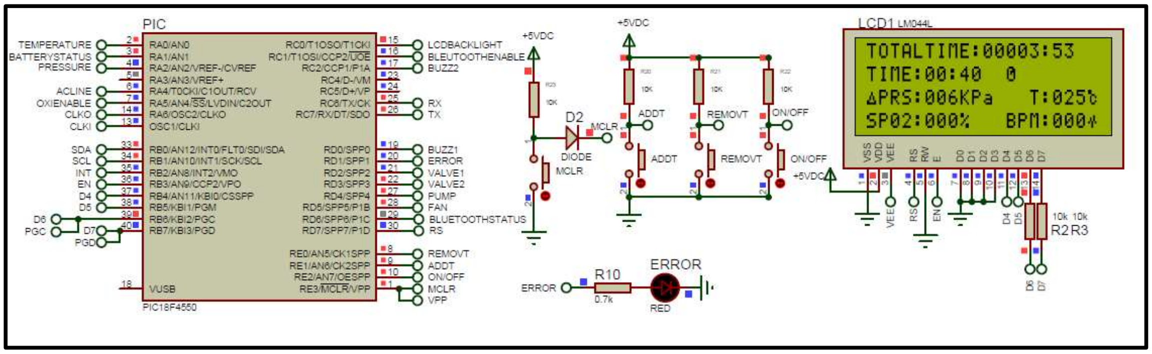


Figure 3.24: Device switch on simulation.

3.8.2. Parameter menu

The Figure 3.25 shows parameter menu allows the user to activate or deactivate Bluetooth module for communication, activate or deactivate oximeter features and reset the device's total operating time. These options allow the user to personalize and control the features of the device.

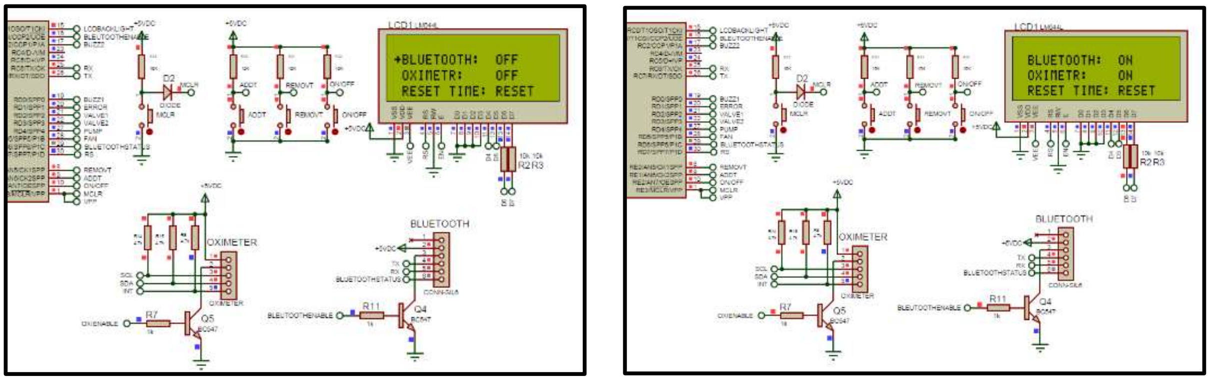
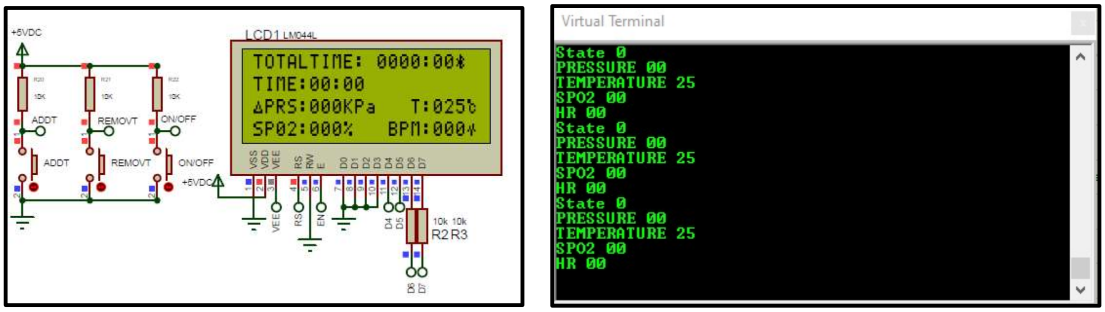


Figure 3.25: Parameter menu simulation.

3.8.3. Bluetooth communication

The figure3.26 below shows the Bluetooth communication process and the data transmitted by the terminal. This communication enables wireless data transfer between the device and smartphone application. The LCD display indicates that the device is successfully connected using Bluetooth



```
State 0
PRESSURE 00
TEMPERATURE 25
SPO2 00
HR 00
State 0
PRESSURE 00
TEMPERATURE 25
SPO2 00
HR 00
State 0
PRESSURE 00
TEMPERATURE 25
SPO2 00
HR 00
```

Figure 3.26: Bluetooth communication simulation.

3.8.4. Battery level

When the battery level is low and needs to be replaced, a battery symbol will appear on the LCD display to remind the user to replace the battery.

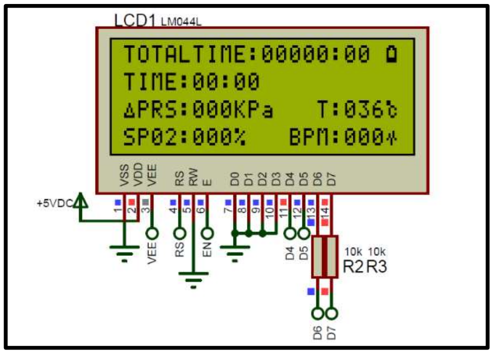


Figure 3.27: Battery low level simulation.

3.8.5. Errors

- **Overheat Under/Overpressure**

When the compressor environment temperature rises above 45 degrees Celsius or under/overpressure conditions occur pressure greater then 20Kpa or less then 6Kpa, the device immediately shutdown operation. An alarm is activated, indicating an error condition, and the error message appears on the LCD display. In addition, a buzzer is activated to provide an audio warning, and a red LED start blinking to provide a visual indication of the error.

- **Line outage**

In the event of a line or power failure, the device follows the same procedure. in the event of a power failure, the device immediately stops operating. display error and release alarm.

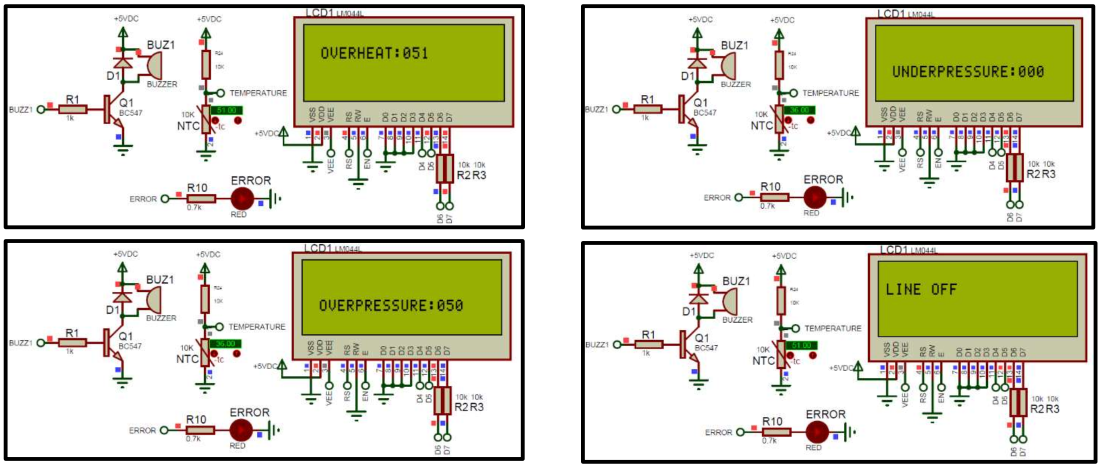


Figure 3.28: Errors simulation.

3.8.6. Power supply board

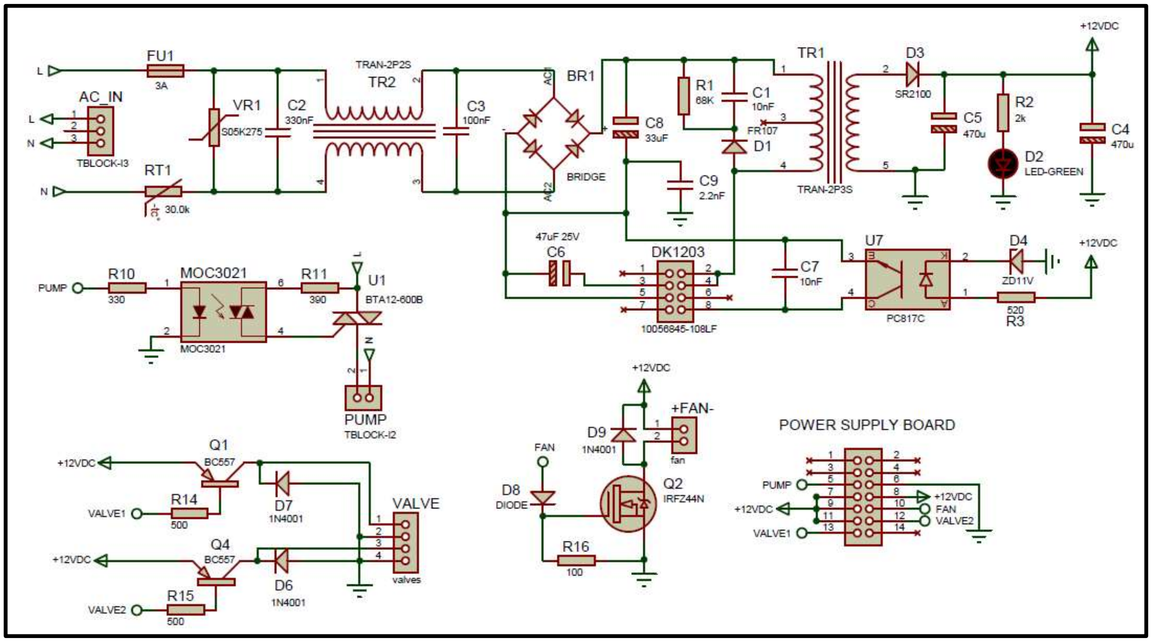


Figure 3.29: Power supply board.

3.9. Practical realization

3.9.1. Control and display board

Figure 3.30 shows the PCB layout with all the components discussed in the previous section of this chapter (input/output interfaces, microcontroller, communication, sensors, etc....).

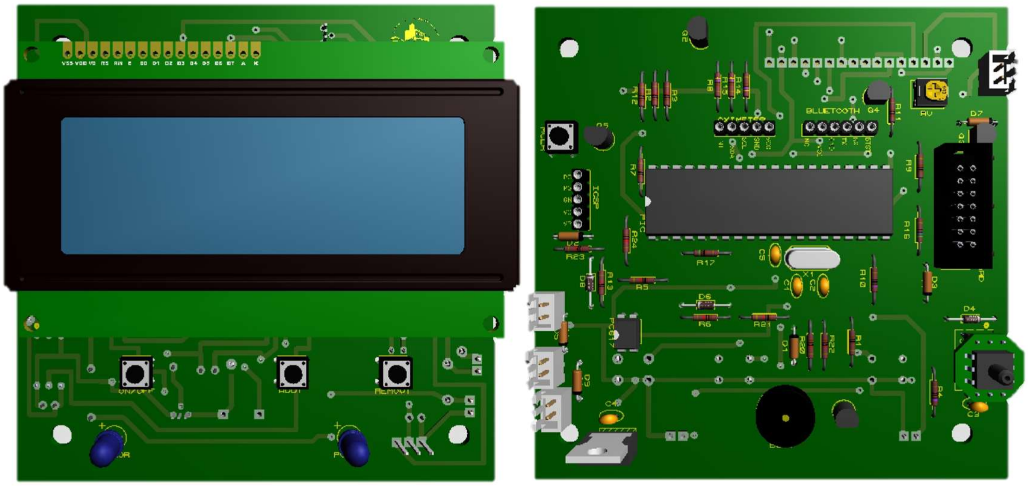


Figure 3.30: 3D module Control and display board.

On the other hand, figure 3.31 shows the same electronic components described above on a single Practical board.

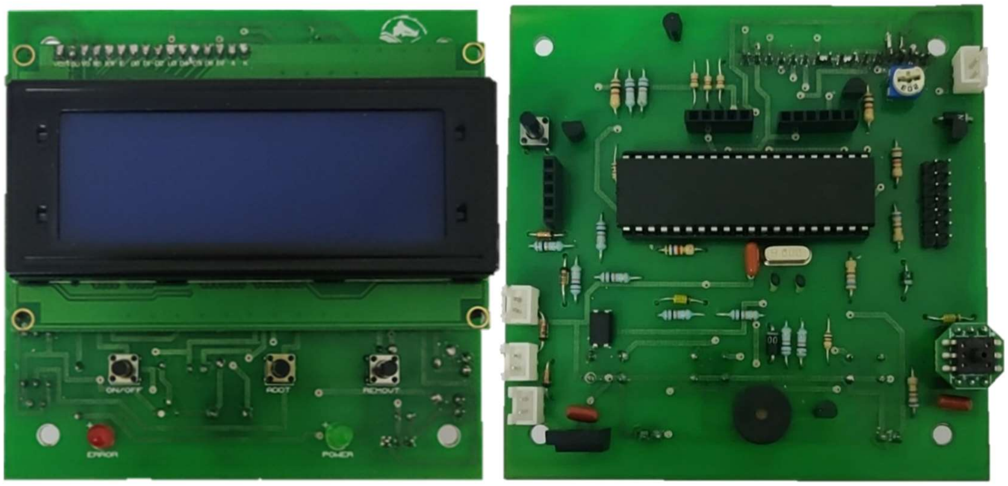


Figure 3.31: Practical Control and display board.

3.9.2. Power supply board

Figure 3.32 shows the PCB layout with all the components discussed in the previous section of this chapter (protection, rectifying, filtering feedback, outputs, etc....).

On the other hand, figure 3.33 shows the same electronic components described above on a single Practical board.

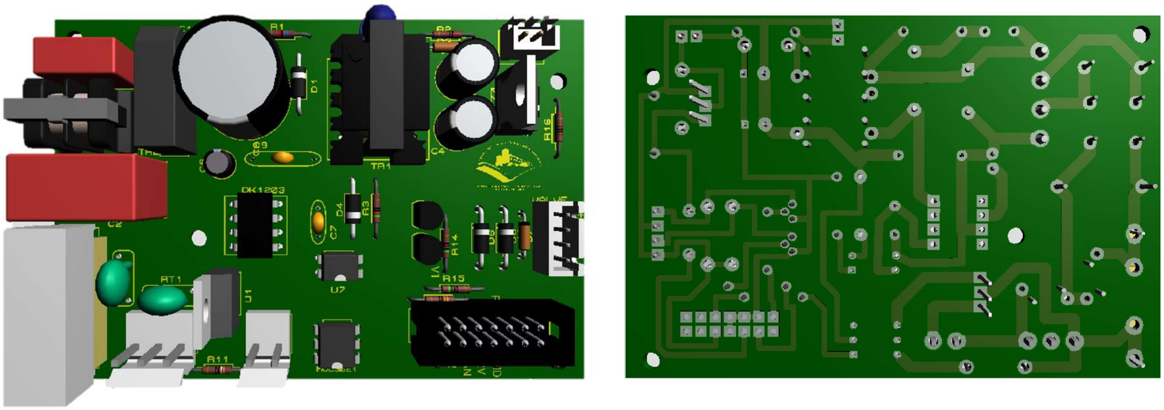


Figure 3.32: 3D module Power supply board.

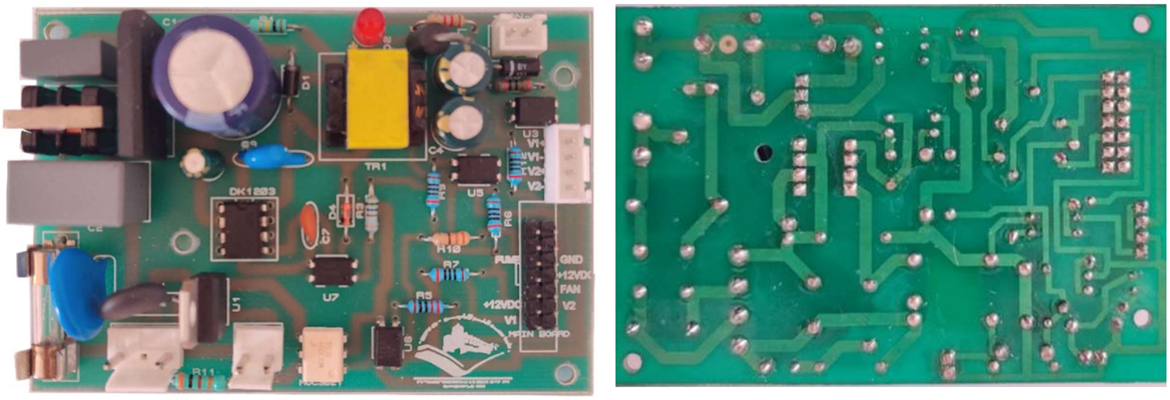


Figure 3.33: Practical power supply board.

3.10. Test and Practical realization

Figure 3.34 shows the control and display board, which is powered by the power supply board. The absence of a time setting is obvious, and the temperature sensor displays the room temperature, while the pressure shows zero.

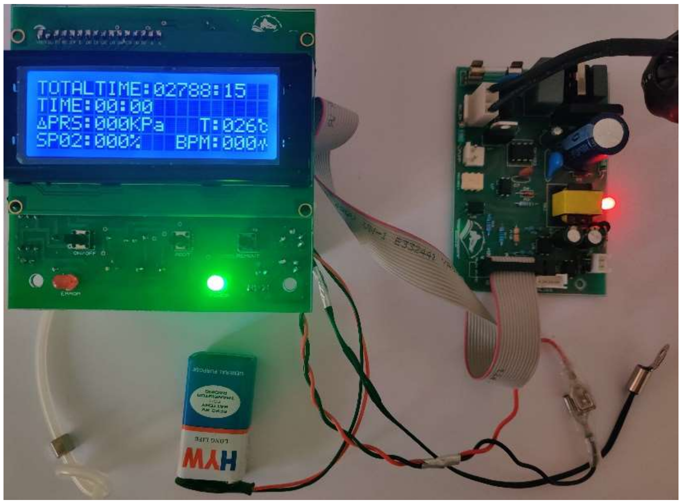


Figure 3.34: Practical realization of power supply and display and control boards.

3.10.1. Temperature calibration

Temperature calibration is the process of checking and correcting the precision of a temperature-measuring device. It consists of comparing the device's readings with a reference source and making the necessary adjustments to guarantee the precision of temperature measurements. the figure 3.35 the reading of our temperature sensors that indicate 31 degrees and reference source shows 31.2 degrees.

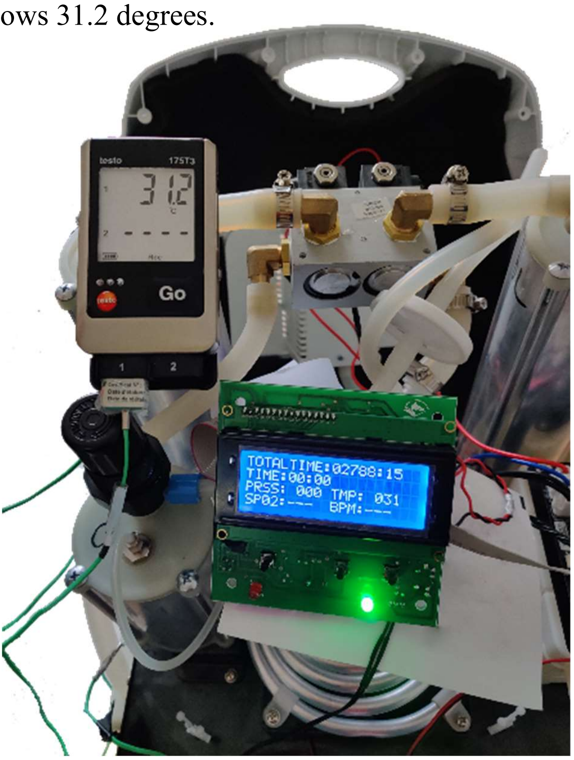


Figure 3.35: Temperature calibration.

3.10.2. Fault detection

When testing failure conditions, we purposely create unusual conditions in order to evaluate how the device reacts. By introducing faults, we test its ability to detect, diagnose and react to them.

Line outage: The first step in a fault state test is to simulate a power failure. This involves disconnecting the power source to evaluate the device's reaction to the loss of power.

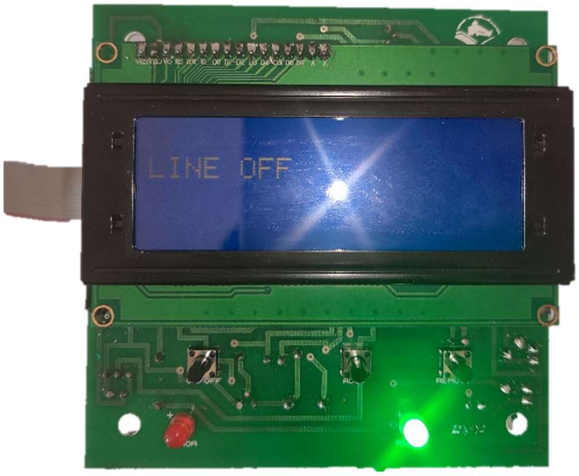


Figure 3.36: Line outage.

Battery backup low level: When testing failure conditions, another important possibility is a low battery level. In the LCD displays a low battery indicator to notify the user that the battery level is low.

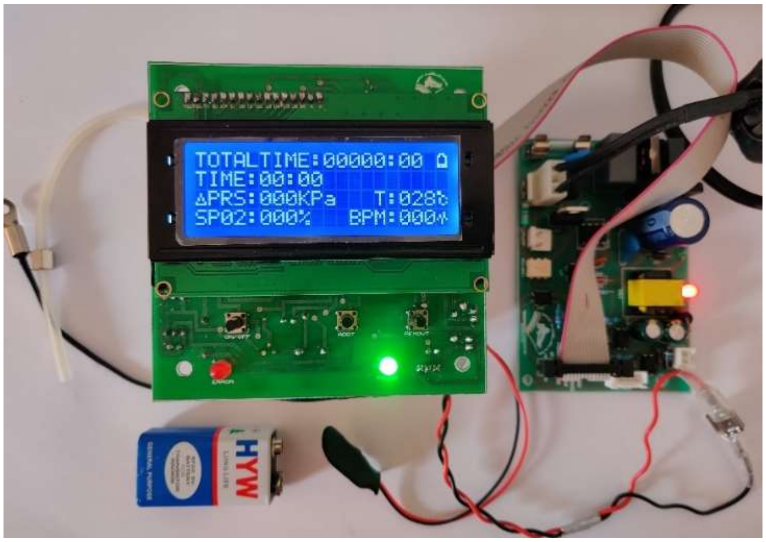


Figure 3.37: Battery low level.

Compressor overheat: The compressor has passed the safety temperature limit, LCD indicating the fault with alarm.

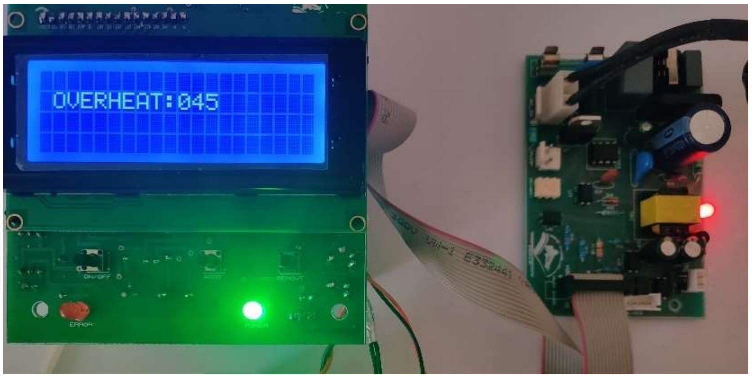


Figure 3.38: Compressor over heat.

Under/overpressure: n occurs when the pressure in a system deviates from the desired range, indicating a change in the system's pressure level.

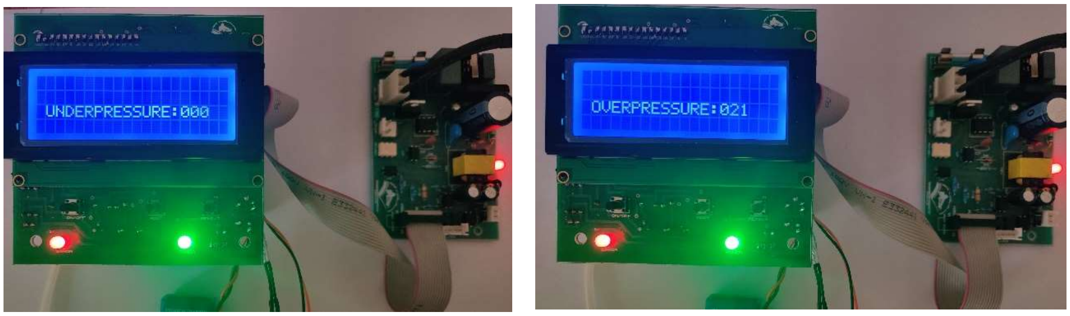


Figure 3.39: Under/overpressure error realization.

3.10.3. Bluetooth communication

In figure 3.40, the Bluetooth feature is shown as activated and successfully connected to an external device. The connection state is indicated on the LCD display, the time is set wirelessly and the POC is switched on, indicated by the clock symbol on the display.

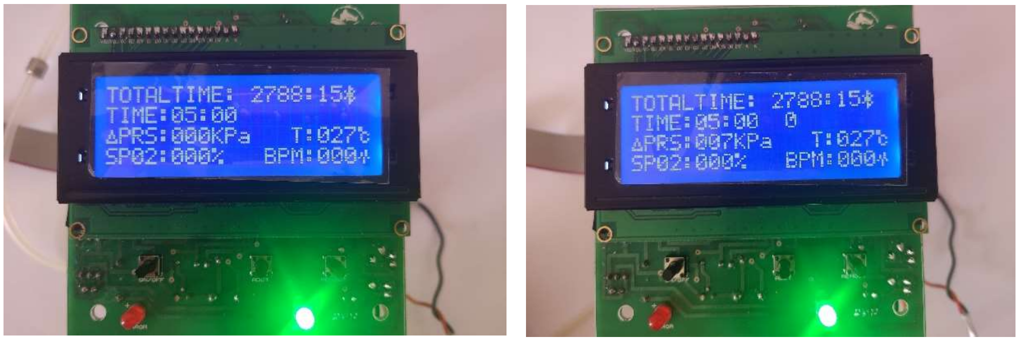


Figure 3.40: Bluetooth communication realization.

3.10.4. Communication application

The app provides real-time updates on the status of the POC, including set time, operational, compressor ambient temperature, tank pressure, SpO2 and heart rate measurements. Users can easily check these parameters through the app, ensuring optimal functionality and patient safety.

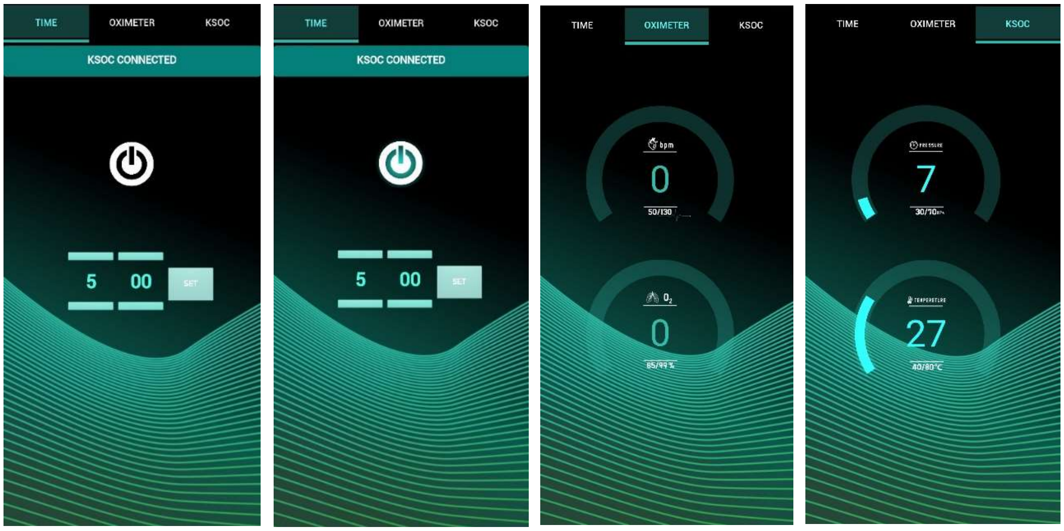


Figure 3.41: The application of a device receiving data.

3.10.5. In circuit serial programming

In-circuit serial programming (ICSP) involves loading a hexadecimal file into the PIC microcontroller. This method allows for programming and updating the microcontroller's firmware without the need to remove it from the circuit.

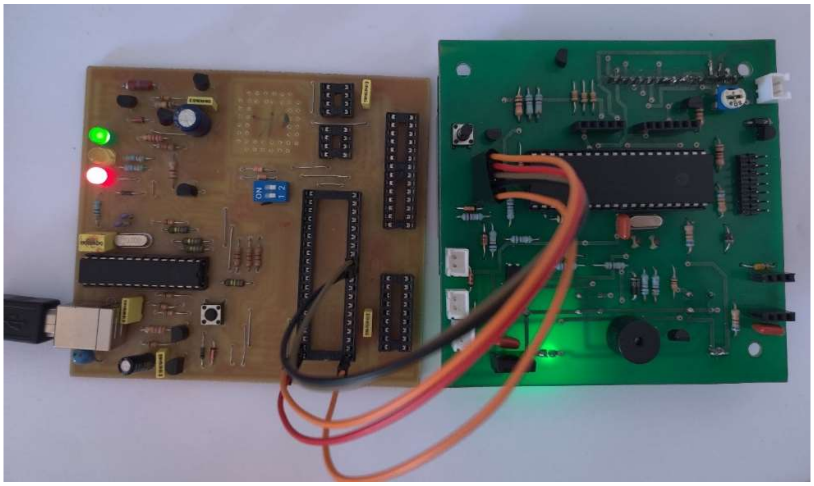


Figure 3.41: Loading a hexadecimal file into the PIC.

3.10.6. Power supply outputs

The power supply board provides 12VDC to the valves and cooling fans (Figure 42), while the compressor is powered by 240VAC (Figure 43).

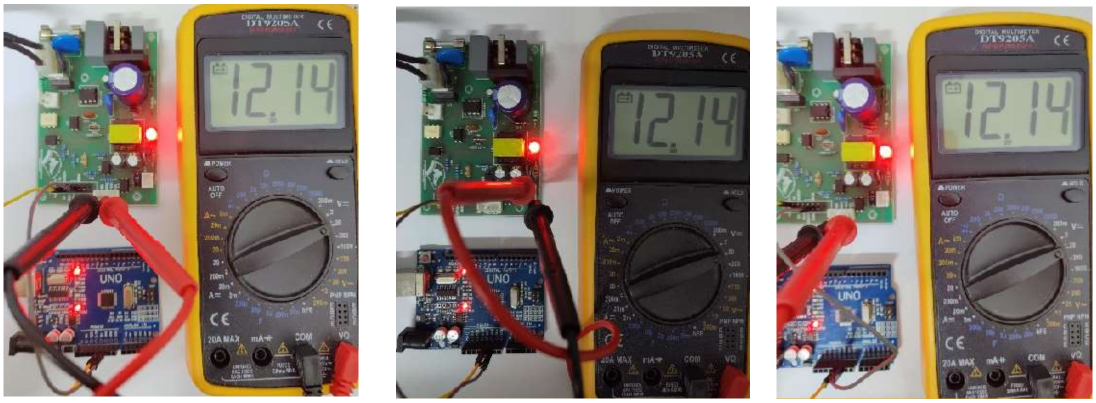


Figure 3.42: 12VDC output.

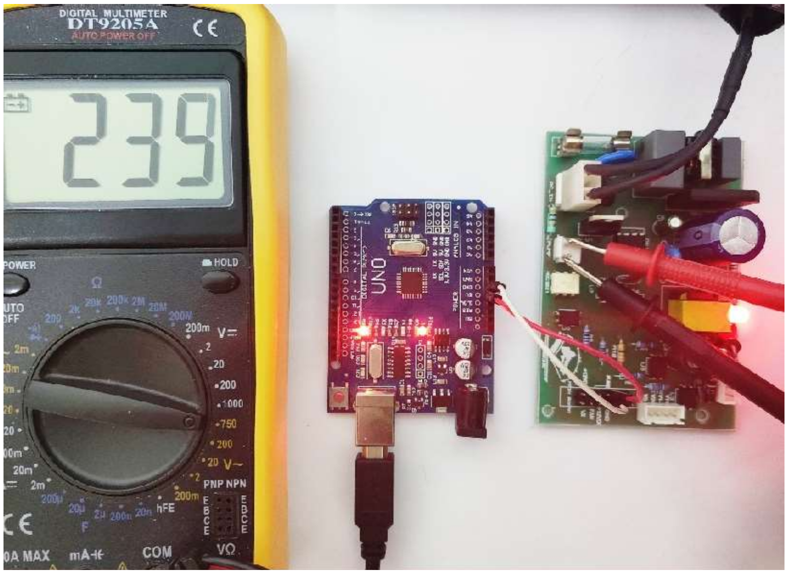


Figure 3.43: 240 VAC output.

3.10.7. The POC implementation

We successfully combined the power supply and display boards with the other components fan, valves, compressor, resulting in a fully functional device (figure 3.44).

Figure 3.44: POC implementation.

Once the control and display board has been added, the buttons and LCD display fit correctly (figure 3.45) shows the POC inside (figure 3.46) shows the POC outside.

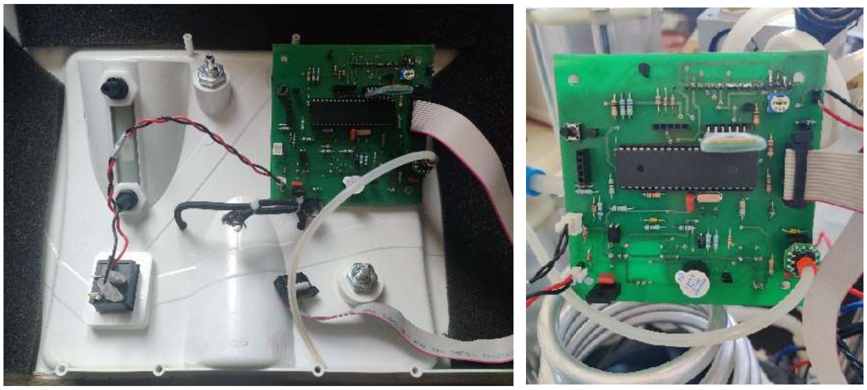


Figure 3.45: Control and display board inside POC.

Figure 3.46: Control and display board from outside.

The figure 3.47 shows the flow meter indicating 7L/min this is acceptable for 10L/min POC device

Figure 3.47: Flow meter.

3.11. Conclusion

In this chapter, in this chapter, we explored electronic schematics and control board algorithm that make it possible to implement PSA technology in the POC device.

The tests and adjustments successfully validated the performance of the POC and confirmed the excellence of the simulation system.

The successful comparison between simulation and practical design results has improved functionality and performance of the POC.

General conclusion and outlook

This project gave us precious experience in studying oxygen concentrators as medical devices. It has helped us understand their design and their role in improving patient care. This experience has further expanded our knowledge of healthcare technologies and their essential role in improving medical performance.

The project began with a study of the principles, technologies of oxygen concentrators. Thorough research articles were carefully reviewed to establish a theoretical basis for the project. This deep exploration laid the foundations for the next stages of the project.

The oxygen concentrator system was modeled using appropriate software tools, taking into account components such as air filters, compressors, valves, molecular sieves, MCU, display screen and oxygen separation technology. This modeled stage provided important information for design optimization before practical implementation.

With the simulation results, the project focused on optimizing the design. By adjusting various parameters such as component size and performance, the project aimed to improve the oxygen concentrator's performance. Simulation enabled to evaluation of different design options.

In practical implementation, the project involved building a physical prototype of the oxygen concentrator. This stage required precise component selection, and flow control systems.

The design was tested and evaluated to ensure that it performed to the highest level. Parameters such as, flow rates, energy consumption, safety and security have been measured and analyzed.

These results will serve as a useful guide for future advances in POC technology, ensuring continued progress and innovation in this field.

We were looking to add an oximeter to our line-up, but unfortunately it didn't work. We hope to be able to solve the problem quickly and have a working oximeter that can accurately measure oxygen saturation. Our aim is to find a solution and get a working device as soon as possible.

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