



## **APPROVAL**

This is to certify that the project on “Oxygen Concentrator Machine by using Pressure Swing Adsorption (PSA)” by Md. Salim (ID No: BME1901017090), Md. Alhaj Uddin (ID No: BME1901017123), Mst. Naima Sultana (ID No: BME1901017133), Md. Shakil (ID No: BME1901017085), Mst. Sufia Akter Sumi (ID No: BME1901017099) has been carried out under my supervision. The project has been carried out in partial fulfillment of the requirement of the degree of Bachelor of Science (B.Sc.) in Mechanical Engineering of the years of 2022 and has been approved as to its style and contents.

-----  
**Prof. MD. Mostofa Hossain**

Professor and Head of Mechanical Engineering Department  
Sonargaon University (SU)

## **DECLARATION**

We hereby declare that the work presented in this project is the outcome of the investigation and research work performed by us under the supervision of Prof. MD. Mostofa Hossain, Professor and Head of Mechanical Engineering Department, Sonargaon University (SU).

Md. Salim

ID No: BME1901017090

Md. Alhaj Uddin

ID No: BME1901017123

Mst. Naima Sultana

ID No: BME1901017133

Md. Shakil

ID No: BME1901017085

Mst. Sufia Akter Sumi

ID No: BME1901017099

## **ABSTRACT**

Oxygen is the fundamental element to survive. Men and animals can't live without oxygen. Which we can realize in Covid -19 situation. A huge number of people suffered from oxygen shortage. The oxygen concentrator machine is a portable oxygen generator, which produce oxygen from environmental air. It worked based on Pressure Swing Adsorption (PSA) system. Generally different types of gases or element contains in our atmosphere. If it can divide as percentage, 78% nitrogen, 21% oxygen, 1% others gases contains in the air. Oxygen concentrator machine separate the nitrogen and oxygen from air then exhaust the nitrogen and supply the patient. It can reduce the dependency to use of oxygen cylinder and help to support the patient in emergency moment.

## **OBJECTIVE**

1. Supply medical oxygen at emergency moment due to the patient who have trouble breathing due to condition like: Asthma.
2. Reduce the dependency on oxygen cylinder.
3. Supply the oxygen at very short time.
4. Produce oxygen at low cost.

## **ACKNOWLEDGEMENT**

At first we give thanks to the Almighty Allah. The project was initiated due to the concern over the lack and shortage of oxygen supplies in epidemic situation, especially in regards to treatment of childhood and older pneumonia. We would like to express our sincere gratitude to our honorable supervisor Prof. MD. Mostofa Hossain, Professor and Head of Mechanical Engineering Department, Sonargaon University (SU), who inspired us in every moment. We are thankful to him for his continuous encouragement, kind co-operation and scholastic guidance all along the project work.

# Table of Contents

LIST OF FIGURES.....	3
LIST OF TABLE .....	4
MATHEMATICAL SYMBOLS .....	5
Chapter – 1 .....	6
INTRODUCTION.....	6
1.1 Introduction.....	6
1.2 Goals and objectives .....	6
1.3 Air Separation Processes.....	7
1.3.1 Adsorption based air separation processes.....	9
1.3.2 Pressure swing adsorption (PSA) process.....	9
1.4 Commercial Medical Oxygen Concentrators for Breathing Patients.....	11
Chapter – 2.....	14
LITERATURE REVIEW.....	14
2.1 Overview .....	14
2.2 Prior Studies on Pressure Drop in a PSA Column .....	14
2.3 Patents on Portable Oxygen Concentrators.....	15
Chapter – 3.....	17
TECHNICAL ISSUES.....	17
3.1 Overview of this chapter .....	17
3.2 Technical Specifications .....	17
3.3 Important terms of Oxygen Concentrator .....	17
3.4 Accessories.....	18
Chapter – 4.....	21
EXPERIMENTAL DESIGN AND METHODOLOGY.....	21
4.1 Overview of this chapter .....	21
4.2 Apparatus, Mountings.....	21
4.3 Theory of PSA.....	27
4.4 Working Principle of PSA .....	27
4.5 Methodology .....	29
Chapter – 5.....	32
DATA AND CALCULATION.....	32

5.1 Adsorption of time .....	32
5.2 Cost Calculation .....	33
5.3 Flow Chart.....	33
Chapter – 6.....	34
CONCLUSION .....	34



## LIST OF FIGURES

1.1: Comparison of respiratory system in healthy human beings and patients .....	7
3.1: Oxygen Mask .....	19
3.2: Nasal Cannula .....	19
3.3: Humidifier Bottle .....	20
3.4: Oxygen Flow Meter .....	20
4.1: Air Filter .....	21
4.2: Air Compressor .....	22
4.3: Stainless steel hose pipe .....	22
4.4: PVC hose pipe.....	22
4.5: Copper Coil .....	23
4.6: Moisture Filter .....	23
4.7: 3 Way Solenoid Valve .....	24
4.8: 2 Way Solenoid Valve .....	24
4.9: Reverse Osmosis (RO) Membrane Casing .....	24
4.10: Pressure Guage .....	25
4.11: 5A Sodium Zeolite .....	25
4.12: Wooden body infrastructure .....	26
4.13: 35238MP Multi-Function Timer circuit .....	26
4.14: DC Fan .....	26
4.15: Element of air .....	28
4.16: Block Diagram of Oxygen Concentrator .....	29
4.17: Zeolite Colum .....	30
4.18: Setup of Equipment .....	31
4.19: Complete Setup of Machine .....	31

## **LIST OF TABLE**

1.1 Comparison of commercially available oxygen therapy options .....	8
1.2 Schematic diagram of a two bed, 4-step PSA process .....	10
1.3 Commercially available oxygen concentrator in Bangladesh .....	13
5.1 Parameters of Experiment .....	32
5.2 Flow Table .....	33

## MATHEMATICAL SYMBOLS

$\varepsilon$	Bed Voidage
$\varepsilon_p$	Particle Voidage
R	Gas Constant
T	Temperature
$P_L$	Product Pressure
$P_H$	Feed Pressure
$d_p$	Adsorbent Size
L	Bed Length
$\mu$	Viscosity of Air
K	Dimensionless Henry's Law Constant
$k_p$	Bed Permeability
$u_z$	Gas Phase Velocity
$\omega$	Wave Velocity
$t$	Time
$\Delta P$	Pressure Drope

# Chapter – 1

## INTRODUCTION

### 1.1 Introduction

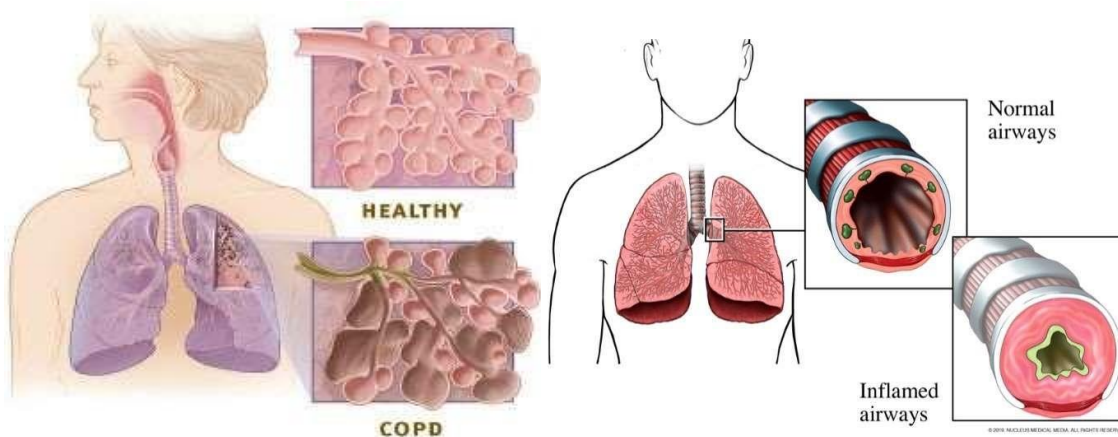
Oxygen is the main requirement to live. Use of oxygen-enriched streams produced from air spans from classical chemical engineering to biological and medical applications. There is a significant demand for portable oxygen supply for personal use by people needing oxygen therapy. Medical conditions in humans such as Chronic Obstructive Pulmonary Disease (COPD) or any types of breathing problems, limit the capacity of the lung to oxygenate blood by breathing atmospheric air. A constant supply of pure oxygen or oxygenenriched air is essential to facilitate breathing for such patients. The demand for portable medical oxygen systems has significantly increased over the last decade because of an increasing number of breathing problems in patients around the world.

One option for shortness of breath patients is to use a small oxygen cylinder for breathing. The other available option is to use a device that draws in air and produces varying degrees of enriched oxygen using pressure-swing adsorption (PSA). which the breathing problems patients can then use to facilitate their breathing. These options, due to the size and weight of the devices, have limited portability that results in restricted mobility for these patients who might otherwise be more physically active. Therefore, an oxygen-concentrating device using atmospheric air as feed that is sufficiently small in size and lighter in weight can significantly improve the quality of life for those people who need oxygen therapy to overcome their lung insufficiency. For this reason, the main focus of current research is to study the feasibility of miniaturization of adsorption-based oxygen concentrating device for personal medical applications of chronic obstructive pulmonary disease patients.

### 1.2 Goals and objectives

Oxygen is a basic requirement in order to save the lives of seriously ill patients. Different kinds of breathing problems such as Hypoxaemia, Asthma, Chronic Obstructive Pulmonary Disease (COPD), Chronic effect on lungs, Damage of lungs and we saw corona virus patient suffer causes difficulty in breathing. It causes the blood is affected by the disease and the blood can't bond by oxygen the limitation of air flow to and from the lungs by narrowing the airways and hence it leads to the damage of lungs and shortness of breath in patients and the oxygen is essential for the treatment of short breathing and should be given to the patient to improve and stabilize blood oxygen saturation levels. The respiratory systems of a healthy adult and that of a COPD affected patient are shown in Figure 1.1. The loss of surface area of air sacs for exchange of oxygen

and carbon dioxide between the air and blood in affected patients is evident from Figure 1.1. The primary causes for shortness of breath diseases are cigarette smoking, long term exposure to smoke and chemical fumes, and air pollution, malnutrition etc. There is no cure for this disease but it can be slowed down by oxygen therapy. Oxygen therapy is a treatment that provides high purity oxygen to affected patients to overcome their lung inefficiency; therefore, the oxygen levels in blood can be maintained. The oxygen therapy options commercially available on the market are liquid oxygen tanks, compressed oxygen tanks and oxygen concentrators, which are summarized in Table 1.1. Liquid oxygen tanks are widely used in hospitals because of their high usage requirements. Liquid oxygen and high pressure cylinders need to be refilled after use and also require special care for storage and handling. Therefore, these options are not safe and economically viable for personal medical applications of shortness of breath patients. In contrast, an oxygen concentrator generates oxygen using ambient air as the feed and continuously delivers oxygen to patients. Therefore, these units have a widespread use for home oxygen therapy and portable personal oxygen.



**Figure 1.1: Comparison of respiratory system in healthy human beings and patients.**

### 1.3 Air Separation Processes

The primary products of air separation, O<sub>2</sub>, N<sub>2</sub> and Ar, are the key commodity chemicals in many manufacturing processes. Air separation is an energy intensive process. There are two primary technologies for air separation into oxygen and nitrogen:

- i. Cryogenic air separation processes
- ii. Non-cryogenic air separation processes
  - a) Adsorption based gas separation processes
  - b) Membrane based gas separation processes

c) Chemical processes

Liquid oxygen	High pressure compressed oxygen cylinders	Oxygen concentrators (Instant use)
Large, small units and does not require electricity	Small, lightweight and does not requires electricity	Onsite, unlimited supply of oxygen; requires electricity
Low temperature storage	High pressure product	Ambient temperature and pressure
Refilling after use	Replacement after use	Refilling not required
Expensive	Expensive	Economical
Requires special equipment and is heavy	Requires special cylinders	Portable units available but are heavy
Hard to handle	Very difficult to handle and not safe	Safest way for oxygen supply
Maintenance required	Requires extreme care	Less maintenance

**Table 1.1: Comparison of commercially available oxygen therapy options**

Cryogenic air separation is the most cost effective and efficient technology currently used for production of large quantities of oxygen and nitrogen with high purity and recovery. It is based on low temperature distillation of oxygen and nitrogen due the difference in their boiling points. Cryogenic air separation plants are usually bulky in size and not suitable for onsite small scale applications such as medical oxygen delivery systems. The first two options, liquid oxygen and compressed high pressure oxygen cylinders in Table 1.1 are obtained from cryogenic distillation of air.

The non-cryogenic processes separate air into oxygen and nitrogen based on differences in the adsorption equilibrium or rate and permeation of air components on adsorbent and membrane materials respectively at room temperature and near ambient pressure. Non-cryogenic air separation processes are small in size, efficient and economical compared to cryogenic plants for the small scale production of oxygen and nitrogen.

Among the non-cryogenic air separation processes, membrane and chemical processes are still developing for producing high purity oxygen from air streams. Since, the invention of synthetic zeolites for air separation, the adsorption based air separation process contribute to more

than 30% of the world oxygen demand in comparison to cryogenic distillation processes for small scale applications.

### **1.3.1 Adsorption based air separation processes**

In an adsorption based air separation process for oxygen, the air fractionation into its primary components is based on selective adsorption of N<sub>2</sub> over O<sub>2</sub> and Ar on zeolite adsorbent materials. The preferential adsorption of N<sub>2</sub> on zeolites is due to the quadrupole moment of N<sub>2</sub> molecules under the influence of a non-uniform charge distribution in the zeolite framework. O<sub>2</sub> and Ar have similar adsorption capacities on zeolite molecular sieves. Consequently, the maximum oxygen purity that can be attained using adsorption based air separation processes is limited to less than 95%. Nonetheless, the zeolite adsorbents are typically used for adsorption based oxygen production from air for small scale applications. However, because the zeolite

adsorbents have a high capacity for the other components of ambient air, H<sub>2</sub>O and CO<sub>2</sub>, the regeneration of the adsorption column is also a critical issue; even a small amount of these polar compounds present in air can significantly reduce the capacity of these zeolite adsorbents for air separation. Therefore, these compounds must be removed from air before entering the column using desiccants such as activated NaX zeolite adsorbents. When dry air is passed through a column packed with a zeolite adsorbent, the N<sub>2</sub> is selectively retained by the solid adsorbent, and O<sub>2</sub>- enriched product gas can be generated at the exit of the column. The adsorbed N<sub>2</sub> is desorbed by lowering the pressure in several ways based on which the adsorption-based air separation processes are classified as follows:

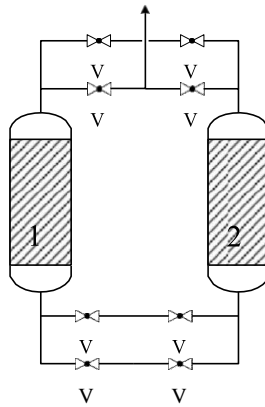
- i. Pressure swing adsorption (PSA)
- ii. Vacuum- pressure swing adsorption (VSA, VPSA or PVSA)
- iii. Rapid pressure adsorption process (RPSA)

The selection of the above processes depends on the nature of the isotherms, working capacity and selectivity of nitrogen over oxygen on the chosen adsorbent. The selectivity of N<sub>2</sub> should be very high to produce high purity O<sub>2</sub> in the adsorption step. Furthermore, the desorption of nitrogen should be readily achieved by lowering the pressure to create enough capacity of the adsorbent for N<sub>2</sub> gas in the subsequent cycle. This will reduce the product purge gas requirement in order to remove the nitrogen from the voids of the zeolite adsorbent before starting the next cycle.

### **1.3.2 Pressure swing adsorption (PSA) process**

The pressure swing adsorption process separates oxygen and nitrogen from air due to the difference in adsorption of oxygen and nitrogen on zeolite adsorbents at two different pressures near and above atmospheric pressure. The high quadrupole moment of nitrogen causes its high

affinity for adsorption over oxygen and argon on zeolite materials. The PSA cycle operates at ambient temperature between super atmospheric pressure, at which the adsorption of nitrogen from air is more and gas enriched in oxygen is delivered from the other end, and atmospheric pressure, at which the bed is regenerated by lowering the pressure to 1 bar causing the adsorbed nitrogen to be released from the adsorbent. It is different from the cryogenic distillation technique for gas separation, which operates at a very low temperature below 0°C. The schematic of the basic Skarstrom cycle for the pressure swing adsorption process is shown in. The cycle consists of two adsorption columns packed with zeolite adsorbent particles and has four steps: pressurization, adsorption, blowdown and purge. The valve operation sequence is shown in the table with Table: 1.2



Step	V1	V2	V3	V4	V5	V6	V7	V8
Pressurization	√	X	X	√	X	X	X	X
Adsorption	√	X	X	√	√	X	√	√
Blowdown	X	√	√	X	X	X	X	X
Purge	X	√	√	X	√	√	√	√

**Table 1.2: Schematic diagram of a two bed, 4-step PSA process.**

Initially both the adsorption columns are saturated with air at 1 atm. In the pressurization step, the column pressure is increased from 1 atm to super atmospheric pressure using air at high pressure from the feed end by opening solenoid valve V1. While bed 1 is in the pressurization step, bed 2 is undergoing blowdown during which the nitrogen is desorbed from the solid zeolite



adsorbent by lowering the inlet column pressure to 1 atm by opening valve V4 and having the rest of the valves in the closed position. In the second step, the high pressure feed air is supplied to the inlet of bed 1 at a constant inlet gas velocity and oxygen enriched gas is delivered at the exit of the column at the column pressure. In this step, the valve V1 is opened to supply the high pressure feed air to the column at constant velocity and high purity oxygen is delivered through valve V5. During this step, bed 2 undergoes the purge step. A part of the oxygen product gas obtained from bed 1 is used to purge the second column in order to remove the desorbed nitrogen from the voids of the zeolite adsorbent by purging the column with high purity oxygen. In this step, valves V7 and V4 are opened and the other valves are closed to purge the column with an enriched oxygen stream from the first bed. In the third step, bed 1 undergoes a blowdown step in which the zeolite adsorbent is regenerated by desorbing the nitrogen adsorbed in previous step by lowering the column pressure to atmospheric pressure during which bed 2 undergoes the pressurization step. In these steps the valves V3 and V2 are opened and the other valves are in the closed position. Finally, bed 1 undergoes the purge step while bed 2 is undergoing the adsorption step. In this step, the valves V3 and V7 are opened to purge column 1 and V2 and V6 are opened to deliver the oxygen rich product at the column exit of the second bed. A part of product gas from bed 2 is used to purge the first bed. The first and second steps, pressurization and adsorption, are referred to as the first half cycle; the third and fourth steps, blow down and purge, are referred to as the second half cycle. While bed 1 is under the first half cycle, bed 2 is under the second half cycle. One complete cycle constitutes all four steps together. Both the adsorption columns repeatedly undergo all these steps in each cycle in order to produce the enrich oxygen stream in adsorption and to desorb the nitrogen in the blowdown and purge steps. The commonly used particle size range in the conventional pressure swing adsorption process is between 0.5 to 2 mm. The process performance is usually measured in terms of oxygen purity, recovery and productivity. Several process variables, bed length, column pressure, inlet gas velocity and cycle times affect the process performance. For the conventional PSA process the effect of pressure drop along the column is not very significant in short laboratory columns packed with larger adsorbent particles. The maximum oxygen product purity obtained using the PSA process is limited to  $< 95\%$ ; the other gas produced is Ar due to same capacity of  $O_2$  and Ar on solid zeolite adsorbents.

## **1.4 Commercial Medical Oxygen Concentrators for Breathing Patients**

Oxygen concentrators are devices to provide oxygen to breathing patients at higher concentration than available in ambient air in order to alleviate their lung inefficiency. The commercially available oxygen concentrators in the market are designed based on adsorptive gas separation of air using zeolites as adsorbents. Since their invention in the early 1970's, tremendous advancement in adsorption technology and synthesis of superior LiX zeolite adsorbents for air separation has reduced their size and improved process performance. Therefore, these concentrators perform much better than the other two options, liquid oxygen tanks and compressed

oxygen cylinders. The main features or specifications of some of the commercially available portable oxygen concentrators are summarized in Table 1.2.

An oxygen concentrator using PSA technology consists of one or more adsorption columns, a compressor and several valves to control the pressure cycling and flow sequence of atmospheric air fed to the system. The adsorption column packed with zeolite adsorbent selectively adsorbs nitrogen over oxygen in the air and delivers high purity oxygen to the patient. The captured nitrogen is desorbed from the bed by lowering the pressure. The adsorption columns and the compressor are the two principal contributing factors to the size and weight of the device. The main issues for size and weight reduction are size reduction of the adsorption column and the compressor. A principal focus in this study is size reduction of the adsorption column.

The oxygen concentrators designed based on a conventional four-step Skarstrom PSA cycle suffer from multi-valve switching and a low production rate per unit mass of adsorbent. Therefore, they cannot be made very compact and lightweight. Although PSA units for concentrating oxygen from air have been developed for small scale medical applications, commercially available units are still not suitable for ambulatory use by an active breathing patient. Therefore, a more compact and lightweight design for an oxygen concentrator is necessary to address the problems associated with its portability and efficiency, which in turn can improve the quality of life for patients.

Model	Company	Size height x width x depth (cm)	Weight (kg)	Purity (%)	Delivery rate (SLPM)	Battery power (hr)
IGO	Devilbiss	49 x 31 x 18	8.6	91±3%	3	2 hr duration, 4 hr charging
Eclipse 3	Sequeal	49 x 31.2 x 18	8.3	90±3%	0.5-3 pulse mode	1.3 hr duration
Evergo	Phillips Respironics	21.6 x 30.5 x 15.2	4.5	89±3%	1-6 pulse mode	3.6 hr duration
Life style	Airsep	21.8 x 15.5 x 9.1	4.4	90±3%	1-5 pulse mode	50 min duration; 2 hr 30min charging

One G <sub>2</sub>	Inogene	27.3 x 10.1 x 24.1	3.3	87%- 96%	1-5 pulse mode	4 hr duration, 4 hr charging
XPO <sub>2</sub>	Invacare	25.4 x 17.8 x10.2	3.3	87%- 96%	1-5 pulse mode	2 hr 30min duration, 3 hr charging
Free style	Airsep	21.8 x 15.5 x 9.1	2.3	90±3%	1-3 pulse mode	3 hr duration, 3 hr charging

**Table 1.3: Commercially available oxygen concentrator in Bangladesh.**

## **Chapter – 2**

### **LITERATURE REVIEW**

#### **2.1 Overview**

In chapter 1, the pressure swing adsorption process (PSA) with high productivity for reducing the size of the adsorption column in an oxygen concentrator was discussed. However, the design and development of PSA processes requires a detailed study of adsorbent characterization. In this chapter, therefore, a detailed overview of the literature available on pressure swing adsorption process (PSA) are presented. A summary on patent literature on portable medical oxygen concentrators has also been presented.

#### **2.2 Prior Studies on Pressure Drop in a PSA Column**

Sundaram and Wankat (1988) studied the effect of pressure drop in pressurization and blow steps of a conventional PSA process. It was shown that the effect of pressure drop along the column was very important in a rapid cycling process due to the shock wave behavior during the short durations of pressurization and adsorption steps. They also reported that the effect of pressure drop was significant even for conventional cycling schemes.

Buzanowski et al., (1989) studied the effect of pressure drop on the wave front propagation in the bed. They neglected the external film resistance and internal mass transfer resistance by choosing a large pore variety of zeolite, 13X zeolite, and small-size adsorbent pellets. They concluded that the pressure drop promoted the spreading of the concentration front in the bed due to the increase in gas velocity. Sereno and Rodrigues (1993) numerically investigated the validity of steady state Darcy's or Ergun equation to predict the pressure drop in an adsorption column during pressurization and de-pressurization steps. They solved the full mechanical energy balance equation and steady state Darcy's or Ergun equation using moving finite volume technique. From the simulation study, they observed that the steady state Darcy's or Ergun equations could be used to model the pressurization of adsorbers.

Kikkinides and Yang (1993) also carried out a theoretical and experimental study on the effect of pressure drop on the dynamics of adsorption in fixed bed under isothermal condition using 13X-PSO<sub>2</sub> zeolite as the adsorbent and oxygen as the adsorbate, and also they extended their theoretical study to include the industrial size adiabatic adsorber. They also considered the axial dispersion term in total pressure balance equation. They solved the model equations using Galerkin finite element method. They also observed that the presence of pressure drop caused an early breakthrough of concentration wave compared to the case with no pressure drop. It was also shown

that the pressure drop could either deflate or inflate the profiles of concentration and temperature depending on certain bed parameters.

Yang et al., (1998) theoretically investigated the effect of pressure drop in a PSA process using Ergun and Darcy's law for the separation of H<sub>2</sub>/CO using 5A zeolite material. They had considered dispersion of pressure in total pressure balance equation, which was a result of incorrectly representing the Fick's law. They observed that the pressure drop effect was significant during pressurization and blow down steps and it caused early breakthrough during adsorption step under nonisothermal conditions and the effect was not significant under adiabatic and isothermal conditions. It was observed that the Ergun equation showed a larger pressure drop and it took long time to reach steady state compared to Darcy's law. They also showed that the effect of pressure drop was negligible on the process performance in a multi-bed PSA process at cyclic steady state.

Ko and Moon (2000) studied the rigorous dynamic simulation and optimization of a simple two step RPSA process. They assumed equal time duration for adsorption and desorption steps. The optimum cycle time, pressure and product oxygen purity obtained by minimizing the power consumption were 14.46 s, 5.57 bar and 96.42%.

Lee et al., (2001) investigated the effect of various operating parameters on the process performance of a small-scale, two-bed, six-step pressure swing adsorption (PSA) process for air separation using 13X zeolite adsorbent. It was observed that the dominant operating factor to determine O<sub>2</sub> purity was changed from adsorption pressure to feed flow rate as the purge to feed ratio was increased. Later in 2005, they studied the separation of oxygen from air using carbon molecular sieves (CMS) adsorbent. They had compared the performance of different cycling sequence of a PSA process. It was observed that the performance of a cycle with pressure equalization was better than the other cycles. In both the papers, they had considered the axial dispersion term in the overall pressure balance equation.

Later, Webley and Todd (2005) studied the use of Ergun equation to represent the pressure drop under adsorbing and non-adsorbing conditions in a column packed with 1.7 mm size particles of LiLSX zeolite pellets. Using the experimentally obtained Ergun parameters to represent the pressure drop, they accurately reproduced the dynamic depressurization and breakthrough pressure profiles and the error between using full momentum balance and Ergun equation was less than 0.1%. They concluded that the Ergun equation could be used to reliably predict the experimental pressure profiles under dynamic adsorbing conditions.

### **2.3 Patents on Portable Oxygen Concentrators**

Krantz and Sircar (1984) patent a medical oxygen concentrator operated on a pressure swing adsorption cycle for home use of high purity medical oxygen supply to the patents. The process consisted of a single bed packed with two layers of molecular sieve adsorbents. The first layer, 13X or 5A zeolite, was for the removal of moisture and CO<sub>2</sub> from air and the second layer,

Ca and Sr exchanged 13X zeolite, was for the retention of nitrogen. They concluded that the oxygen concentrator was capable of delivering more than 90% pure oxygen for the desired medical administration by the needy patients.

Dubois et al., (2003) filed a patent on portable oxygen concentrator, which was designed based on PSA technology using Lithium exchanged zeolite. They proposed that a portable oxygen concentrator was designed by combining certain technical advantages like short production cycle, small adsorbent particles, high nitrogen selective adsorbents and permitting the product oxygen flow rate as required by the patient. The portable oxygen concentrator proposed by them was capable of producing 50% to 90% oxygen from air and weighed around 10 kg.

McCombs et al., (2006) patented a compact, light-weight two-bed oxygen concentrator operated on PSA cycles for ambulatory applications of breathing patients. The oxygen product purity was greater than 90% at product flow rate of 3 SLPM. The overall weight of the device was only about 5 lb.

Whitley et al., (2007) has developed a dual mode medical oxygen concentrator comprising a portable oxygen generator and stationary base unit. The portable unit could be independently operated to generate oxygen at low flow rates for ambulatory use of active COPD patients. They concluded that the portable unit could deliver 0.5 to 3 SLPM of 85% pure oxygen whereas the coupled portable and stationary unit would generate 0.5 to 5 SLPM of oxygen at the same purity.

A pressure swing adsorption based portable oxygen concentrator has been patented by Atlas et al., (2007) and in which the adsorber was packed with two layers of adsorbents, Oxysiv and OxysivMDX. An oxygen conserver was used to regulate the flow of high purity oxygen to the patient. They stated that the oxygen concentrator delivered a maximum of 100% pure oxygen at a rate of 0.9 SLPM, and it had a total weight of 10 lb, a volume of 800 in<sup>3</sup> and a battery life of around 8 hr.

## **Chapter – 3**

### **TECHNICAL ISSUES**

#### **3.1 Overview of this chapter**

In chapters 1 and 2, the basic concept of an oxygen concentrator has been described. In this chapter, the technical issues detailed including the critical issues related to sizing, sensing, measurement, control, technical specifications.

#### **3.2 Technical Specifications**

The following specifications define requirements for stationary oxygen concentrators that are appropriate for the treatment of hypoxaemia in developing countries. It should be noted that these specifications are intended to be used in conjunction with the current standard for oxygen concentrators, ISO 80601-2-69:2014 of the Medical Electrical Equipment – Part 2-69: Particular requirements for basic safety and essential performance of oxygen concentrator equipment. Unless otherwise noted, the following is specified at standard temperature and pressure, dry (STPD). STPD is defined as 101.3 kPa at an operating temperature of 20 °C, dry and the oxygen concentrator should be capable of delivering a continuous flow at a concentration of oxygen greater than 82%.

#### **3.3 Important terms of Oxygen Concentrator**

##### **1. Flow Control**

- The oxygen concentrator should be equipped with at least one built-in flowmeter with flow-rate control. If the oxygen concentrator is equipped with more than one flowmeter, each shall incorporate independent flow-rate control.
- For pediatric use, the flowmeter shall be capable of providing a minimum flow rate of at least 0.5 LPM.
- The oxygen concentrator shall be prevented from providing a flow rate greater than the maximum rated flow rate.
- The flowmeter shall provide continuous flow-rate control, with markings from 0 LPM to the maximum rated flow rate, at a minimum of 0.5 LPM intervals.
- The oxygen concentrator shall be capable of generating at least 55 kPa at all flows, up to the maximum rated flow.

##### **2. Indicators and alarms**

- The oxygen monitor shall indicate when the oxygen concentration is less than 82%.
- The oxygen concentrator shall incorporate alarms for alerting the user of fault conditions such as:

- Low oxygen concentration (<82%)
- No flow
- High/low pressure
- Power supply failure
- High temperature.

### 3. Outlets

- The oxygen concentrator should have at least one oxygen outlet for direct attachment of oxygen delivery tubing.

### 4. Enclosure

- The oxygen concentrator should incorporate gross particle filters to prevent dust and grime from entering the enclosure and air inlet.
- The oxygen concentrator shall produce no more than 50 dB(A) of noise when operating.

### 5. Power

- The oxygen concentrator shall have a power efficiency of  $\leq 70$  W/LPM.

## 3.4 Accessories

### 1. Oxygen Mask

Oxygen Mask provides a way to transfer breathing oxygen gas from storage tank to lungs. It connected to the storage tank of oxygen concentrator.

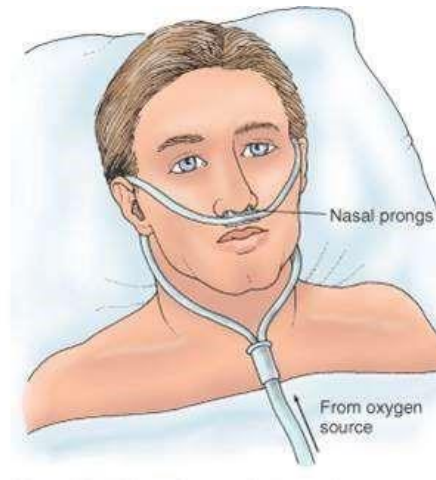


**Figure 3.1: Oxygen Mask.**



## 2. Nasal Cannula

The nasal cannula is a medical device to provide supplemental oxygen therapy to people who have lower oxygen levels.



**Figure 3.2: Nasal Cannula.**

## 3. Humidifier Bottle

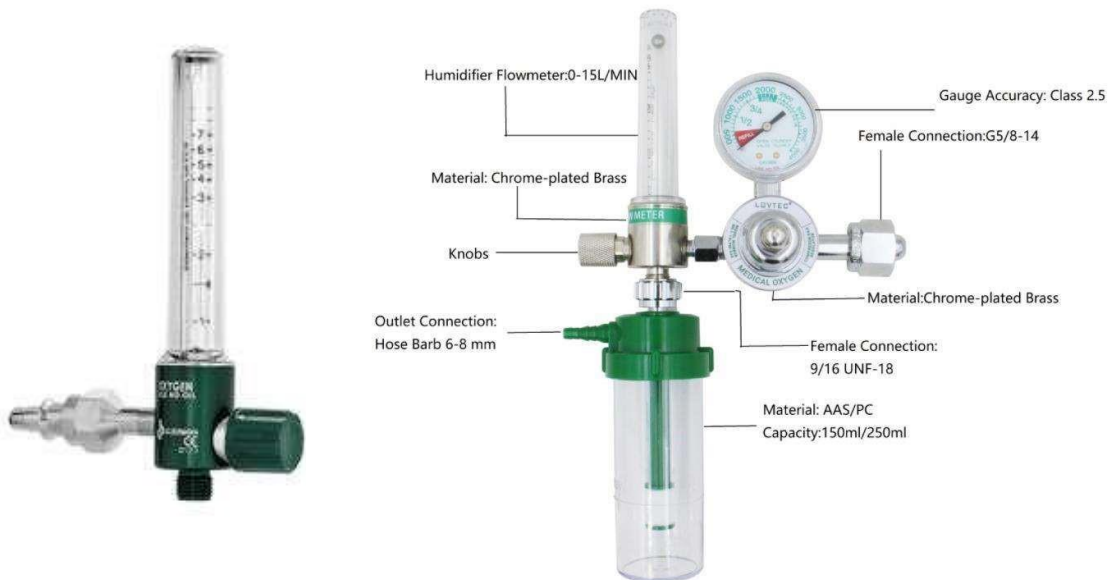
Dry oxygen is harmful for health. Humidifier bottle is required to humidify the oxygen supplied to the oxygen concentrator.



**Figure 3.3: Humidifier Bottle.**

4. Oxygen Flow Meter

Oxygen Flow Meter is a device that indicates, control, and regulates the flow rate of oxygen and it is connected to the oxygen cylinder.



**Figure 3.4: Oxygen Flow Meter**

## **Chapter – 4**

# **EXPERIMENTAL DESIGN AND METHODOLOGY**

### **4.1 Overview of this chapter**

In this chapter, the experimental design, mountings, and setup are described.

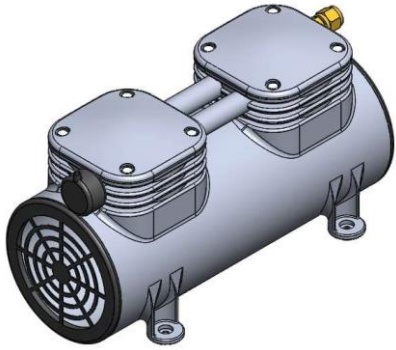
### **4.2 Apparatus, Mountings**

- **Air Filter**  
This is the first device of the machine that removes dust particles and inlet the fresh air into the compressor.



**Figure 4.1: Air Filter**

- **Compressor:**  
The air compressor is a mechanical device that increases the pressure of the air or gas by reducing its volume. Model: JR550, 2.6Am, 220v, 50HZ, 550W



**Figure 4.2: Air Compressor**

- Hose pipe:  
20 mm stainless steel hose pipe, 10mm pneumatic PVC hose pipe.

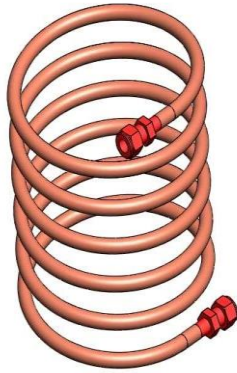


**Figure 4.3: stainless steel hose**



**Figure 4.4: PVC Hose Pipe**

- Copper Coil  
The copper coil is the best heat exchanger. When the compressor compresses the air then it increases the heat of the air. The copper coil is connected to the exhaust port of the compressor by stainless steel. Where copper coil worked as a heat exchanger. 10 mm copper pipe is used in this experiment. Pipe dia: 10mm



**Figure 4.5: Copper Coil**

- **Moisture Filter:**  
The Moisture filter is a device that removes moisture or water particle from the air.  
Model: AW2000-02D.



**Figure 4.6: Moisture Filter**

- **Solenoid Valve:**  
The solenoid valve is an electrical pneumatic valve. It is used to switch and controls the direction of airflow. Here two types of solenoid valves are used.

3 way solenoid valve

Airtac

Model: 3V210-08-NC

DV 24V, 4.8W

2 way solenoid valve

Airtac

Model: 2V025

DV 24V, 3.5W



**Figure 4.7: 3 way solenoid valve**



**Figure 4.8: 2 way solenoid valve**

- **Reverse Osmosis (RO) Membrane Casing:**  
Some cylinders need to make a Zeolite column and oxygen storage tank. In this experiment, we have used reverse osmosis or RO membrane casing as the column and oxygen storage tank or cylinder.



**Figure 4.9: Reverse Osmosis (RO) Membrane Casing**

- **Pressure Gauge:**  
The pressure gauge is a device that is used to measure the speed or pressure of fluid or gas or air.



**Figure 4.10: Pressure Gauge**

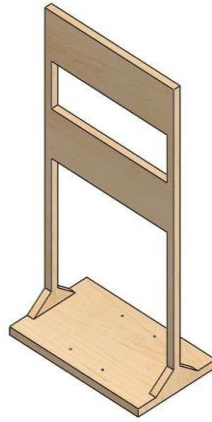
- **Molecular Sieve:**  
This is the main component to make an oxygen concentrator. In this machine, sodium zeolite is used. Zeolite traps the nitrogen and releases the oxygen from supplied air. 13X Zeolite Molecular Sieve, Grain Size: 0.8-1.2mm.



**Figure 4.11: 5A Sodium Zeolite**

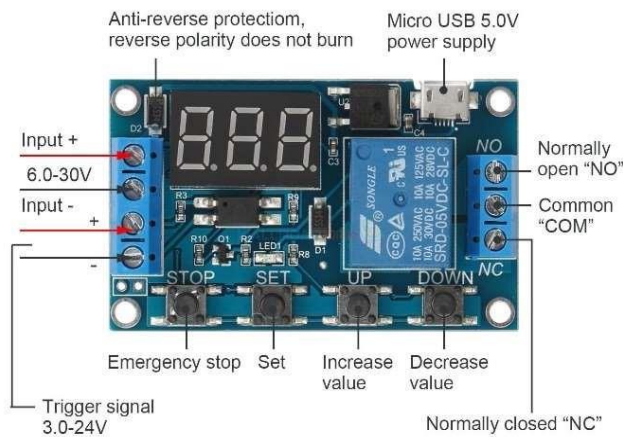
Body Frame:

Wooden body frame is used in this experiment because wood is light weight and easy to change the infrastructure.



**Figure 4.12: Wooden body infrastructure**

- Circuit and electrical equipment  
Multi-function timer circuit (Model: 35238MP), 2 piece 12V DC Fan, 12V & 24V DC power adapter, Some electrical wire, Switch board etc.



**Figure 4.13: 35238MP Multi-function timer circuit**



**Figure 4.14: 12 DC Fan**



### 4.3 Theory of PSA

Pressure swing adsorption or PSA is a process that separates single gases from a gas mixture. PSA is a non-cryogenic air separation process that is commonly used in commercial practice.

- It is an economic and reliable method for separating many gases and achieving a very high purity level for them.
- PSA is mainly employed in the chemical and petrochemical processes.
- It is used to recover hydrogen from coking or conversion gases or to separate oxygen and nitrogen from the air.
- In the process, gases are separated under pressure based on the species' molecular characteristics and affinity for an adsorbent material.
- It operates at near-ambient temperatures which is in contrast to the cryogenic distillation techniques of gas separation, which takes place at very low temperatures.
- Specific adsorbent materials (e.g., zeolites, molecular sieves, activated carbon, etc.) are used as a trap, preferentially adsorbing the target gas species at high pressure. The process then swings to low pressure to desorb the adsorbed material.
- The adsorption process is based on gas molecules binding to an adsorbent material.
- The adsorbent bed is specially selected depending on the gas to be absorbed.
- Ideally, only the gas to be separated is adsorbed, while all other gases in the mixture pass through the adsorbent bed.

### 4.4 Working Principle of PSA

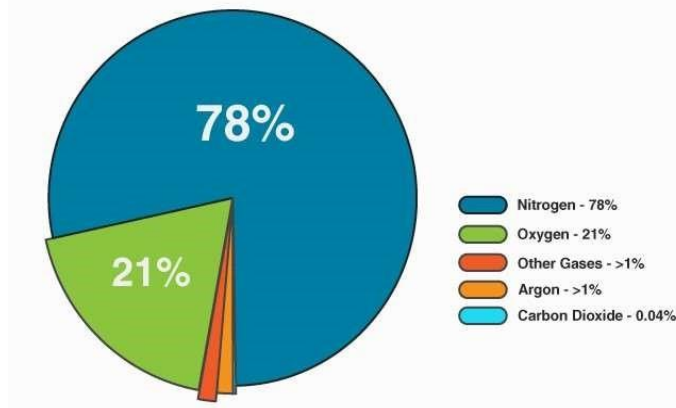
First, air from the ambient atmosphere is compressed into high-pressure air. This gas is then transferred into a vessel or column which is filled with the adsorbent material such as zeolite. The selection of the adsorbent depends on the gas to be extracted. This system is then pressurized and depressurized cyclically, wherein the gas will gradually leave the column first, followed by the other gases.

There are four main phases of the pressure swing adsorption process:

1. Adsorption: The adsorber starts off pressurized with pure gas. The impure gas is fed into the column which contains the adsorber. Adsorption takes place and the pure gas is released from the top of the column. This takes place until the adsorber has reached its adsorption capacity.
2. Depressurization: The adsorber is depressurized over in several small steps to recover additional pure gas still in the adsorber. Once all pure gas has been recovered, the desorbed impurities are dumped into the PSA off-gas line.

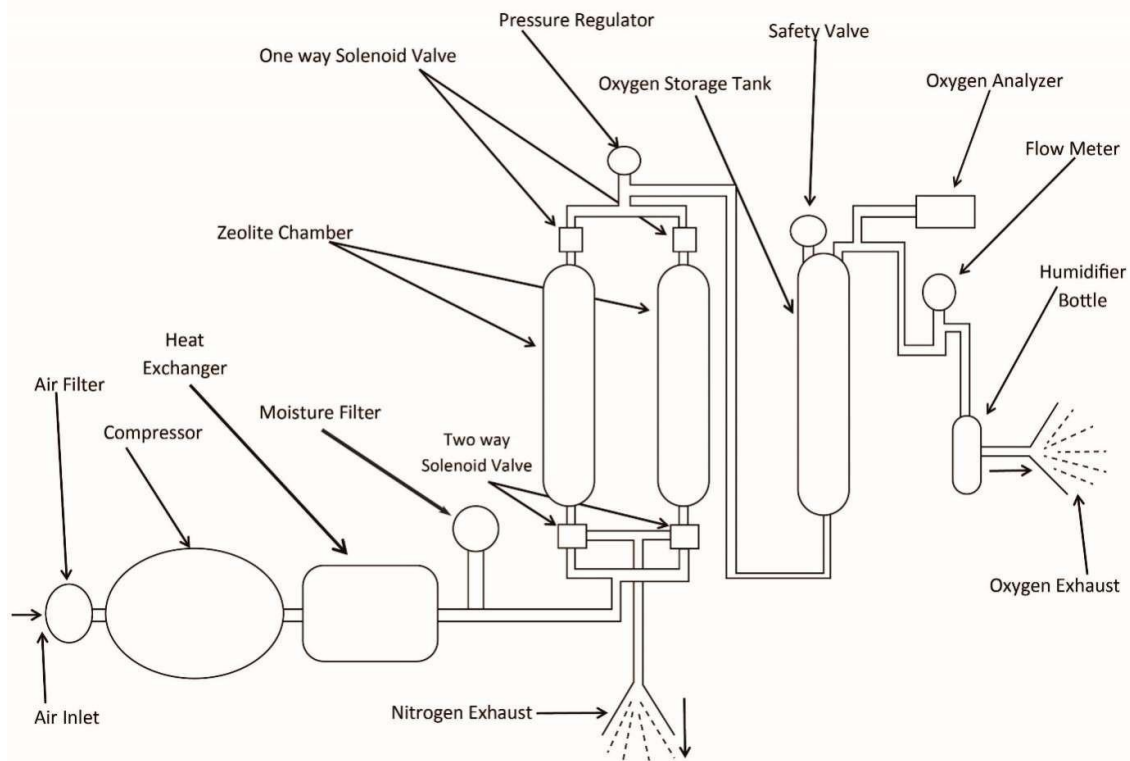
3. Regeneration: The adsorbent is purged with high-purity gas at constant off-gas pressure to further regenerate the adsorbent bed.
4. Repressurization: The adsorber is repressurized with pure gas and is now ready to receive more feed gas to start the process over.

This process is being used to generate medical oxygen to supply to the patient. The air surrounding us contained 21% oxygen, 78 % nitrogen, 1% argon, 0.04% carbon dioxide, and 1% other gases the element percentage chart of air is given in figure: 4.13. The pressure swing adsorption (PSA) process is used to separate various gases from the air. It is used as a substitute for compressed-cylinder storage, which is the primary oxygen source for any hospital. Hospitals and medical applications such as oxygen concentrators require oxygen purity to be between 95 – 99%, and the PSA process can produce oxygen at this purity level.



**Figure 4.15: Element of air**

In PSA system the air goes through into the air filter and the compressor. Then the compressed hot air reduces the heat by the heat exchanger. After that, the cooled air goes through the moisture filter to remove the moisture from the air. Then the moisture-free air goes through the Zeolite chamber. In the Zeolite chamber, the Zeolite trapped the nitrogen and release the oxygen from air. Then the released oxygen will be stored in the oxygen storage tank. The oxygen storage tank also connected to patient oxygen mask and flow meter. The patient take oxygen from the oxygen storage tank by oxygen mask. The block diagram shown figure: 4.16.

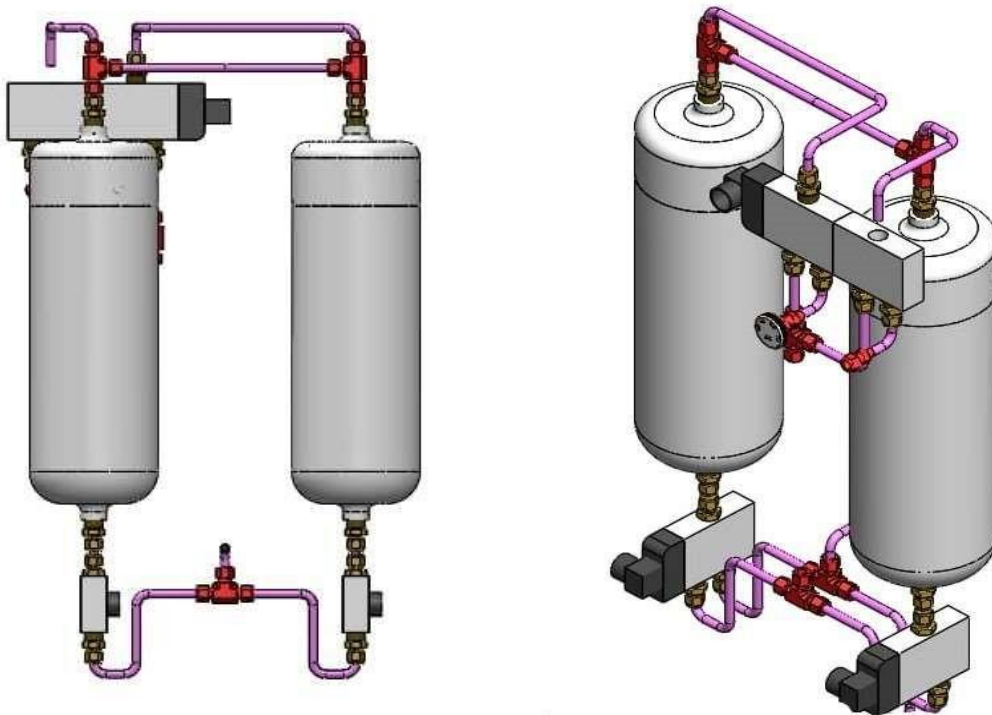


**Figure 4.16: Block Diagram of Oxygen Concentrator**

## 4.5 Methodology

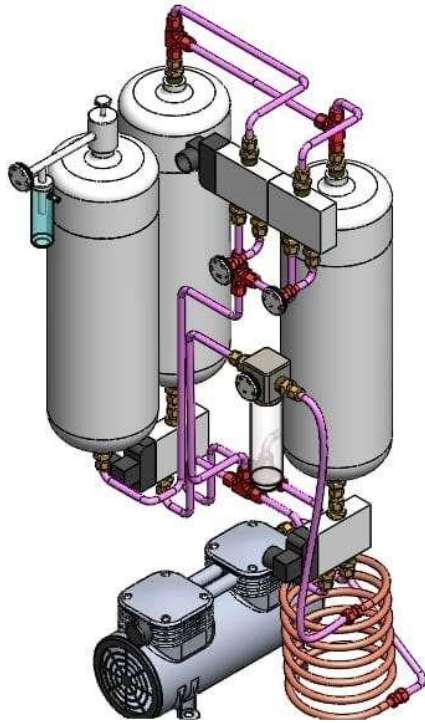
The installation and setup procedure is given below:

1. At first the air filter connect properly to the inlet port of the compressor.
2. A stainless steel flexible hose pipe connect to the exhaust port of compressor and the other side of hose pipe connect to a copper coil by gas welding to prove the air leakage which reduce the heat from the compressed air.
3. The other end of copper coil connect to the moisture filter which removes the water particle and moisture from cooled air.
4. The solenoid valve and the RO casing connect to the outlet the moisture filter by the PVC hose pipe.



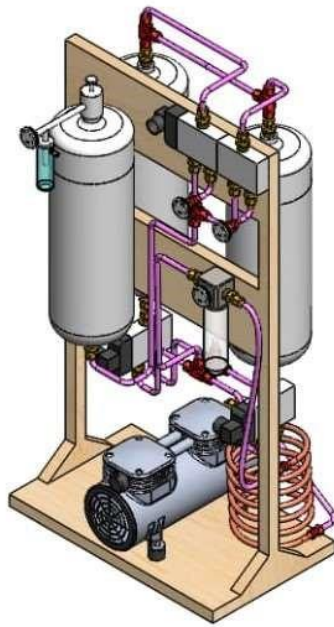
**Figure 4.17: Zeolite Column**

5. Fill the two column by Sodium Zeolite.
6. Connect the oxygen storage tank to the Zeolite column by the hose pipe.
7. Connect the oxygen flow meter on the oxygen storage tank.



**Figure 4.18: Setup of Equipment**

8. Setting the full setup on the wooden infrastructure.



**Figure 4.19: Complete Setup of Machine**

## Chapter – 5

### DATA AND CALCULATION

#### 5.1 Adsorption of time

Design for 5 LPM and purity.

##### Parameters

1. Feed air ratio	79:21
2. $\varepsilon$ (Bed Voidage)	0.33
3. $\varepsilon_p$ (Particle Voidage)	0.35
4. R (Gas Constant)	82.05 atm cc/mol k
5. T (Temperature)	298.15 k
6. P (Product pressure)	1 atm = 14.695 psi
7. P (Feed pressure)	2 atm = 29.391 psi
8. d (Adsorbent size)	0.05 cm
9. L (Bed length)	20 cm
10. $\mu$ (Viscosity of air)	$1.8 \times 10^{-10}$ atm s = $2.64 \times 10^{-9}$ psi s
11. K (Dimensionless Henry's Law Constant) for O	$5.32 \times 10^{-4}$

**Table: 5.1 Parameters of Experiment**

Bed permeability, [10]

$$k_p = \frac{d_p^2}{150} \left( \frac{\varepsilon}{1-\varepsilon} \right)^2 = \frac{(0.05)^2}{150} \times \left( \frac{0.33}{1-0.33} \right)^2 = 4.043 \times 10^{-6} \text{ cm}^2$$

Gas Phase velocity ( $\text{cm}^3 / \text{s}$ ), [11]

$$u_z = -\frac{k_p}{\mu} \Delta p = -\frac{4.043 \times 10^{-6}}{2.64 \times 10^{-9}} \times (1.0206) = -1559.507 \text{ inch}^3/\text{s} = 3961.14 \text{ cm}^3/\text{s}$$

Wave velocity ( $\text{cm}^3 / \text{s}$ ), [12]

$$\omega = \frac{u_z}{\left[ 1 + \frac{1-\varepsilon}{\varepsilon} K \right]} = \frac{3961.14}{\left[ 1 + \frac{(1-0.33)}{0.33} \times 5.32 \times 10^{-4} \right]} = 3961.14 \text{ cm}^3 / \text{s}$$

Time of adsorption , [13]  $t = \frac{L}{\omega} = \frac{20}{3961.14} = 0.0050 = 5\text{s}$

## 5.2 Cost Calculation

Equipment

1. Compressor.....	550Wh
2. 2 Way solenoid valve (2 piece).....	$2 \times 4.8 = 9.6Wh$
3. 3 Way solenoid valve (2 piece).....	$2 \times 3.5 = 7Wh$
4. 12 Volt, 250mAh Fan (2 piece).....	$2 \times 3 = 6Wh$
5. <u>Timer circuit.....</u>	<u>5Wh</u>
Total consumed energy.....	577.6Wh

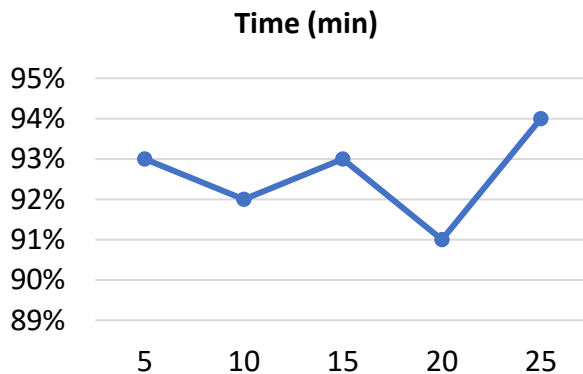
Let,

Per unit electric energy cost 6 Tk

$$\text{Machine operation cost per hour} = \frac{577.6 \times 6}{1000} = 3.4656 \approx 3.5 \text{ Tk}$$

Hence, Oxygen supply cost per hour  $\approx 3.5$  Tk.

## 5.3 Flow Chart



Oxygen %	Time (min)
93	5
92	10
93	15
91	20
94	25

Table: 5.2 Flow Table

## **Chapter – 6**

### **CONCLUSION**

Oxygen is the main requirement to live on the earth. When reduce the power to take oxygen from the normal atmosphere of a person. Then he needs to take oxygen from another source such oxygen cylinder. The oxygen cylinder is costly and sometimes it can be unavailable. The solution of this problem can be a portable oxygen generator machine such as an oxygen concentrator. It can provide oxygen to patient at any environment. So the oxygen concentrator is very useful of people.



## Reference

1. Ashma.bds.uchicago.edu/sample-page/chronic-obstructive-pulmonary-lung-disease-copd
2. ADSORPTION BASED PORTABLE OXYGEN CONCENTRATOR FOR PERSONAL MEDICALAPPLICATION BY VEMULA RAMA RAO.  
NATIONAL UNIVERSITY OF SINGAPORE, 2011, Page: 3
3. ADSORPTION BASED PORTABLE OXYGEN CONCENTRATOR FOR PERSONAL MEDICALAPPLICATION BY VEMULA RAMA RAO.  
NATIONAL UNIVERSITY OF SINGAPORE, 2011, Page: 4
4. ADSORPTION BASED PORTABLE OXYGEN CONCENTRATOR FOR PERSONAL MEDICALAPPLICATION BY VEMULA RAMA RAO.  
NATIONAL UNIVERSITY OF SINGAPORE, 2011, Page: 5
5. ADSORPTION BASED PORTABLE OXYGEN CONCENTRATOR FOR PERSONAL MEDICALAPPLICATION BY VEMULA RAMA RAO.  
NATIONAL UNIVERSITY OF SINGAPORE, 2011, Page: 6
6. ADSORPTION BASED PORTABLE OXYGEN CONCENTRATOR FOR PERSONAL MEDICALAPPLICATION BY VEMULA RAMA RAO.  
NATIONAL UNIVERSITY OF SINGAPORE, 2011, Page: 8
7. ADSORPTION BASED PORTABLE OXYGEN CONCENTRATOR FOR PERSONAL MEDICALAPPLICATION BY VEMULA RAMA RAO.  
NATIONAL UNIVERSITY OF SINGAPORE, 2011, Page: 10
8. ADSORPTION BASED PORTABLE OXYGEN CONCENTRATOR FOR PERSONAL MEDICALAPPLICATION BY VEMULA RAMA RAO.  
NATIONAL UNIVERSITY OF SINGAPORE, 2011, Page: 26
9. ADSORPTION BASED PORTABLE OXYGEN CONCENTRATOR FOR PERSONAL MEDICALAPPLICATION BY VEMULA RAMA RAO.  
NATIONAL UNIVERSITY OF SINGAPORE, 2011, Page: 35
10. Wiley Inter Science (interscience.wiley.com), Page: 358
11. Wiley Inter Science (interscience.wiley.com), Page: 358
12. AIChE Journal, February 2010
13. AIChE Journal, February 2010