A Project Report

on

"Design & Manufacturing of Low-Cost Oxygen Concentrator"

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Submitted in partial fulfillment of the requirement for the degree of B. Tech. in Mechanical Engineering

Deogiri Institute of Engineering and Management Studies, Aurangabad

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CERTIFICATE

This is to certify that the Project entitled

"Design & Manufacturing of Low-Cost

Oxygen Concentrator"

Submitted by

Kaustubh Sonukale (41247)

Has completed as per the requirements of
Dr. Babasaheb Ambedkar Technological University, Lonere.

In partial fulfillment of
Degree of B. Tech. in Mechanical Engineering
For the academic Year 2021-2022

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Project Approval Sheet

By

Examiners

This is to certify that the Project work entitled

"Design & Manufacturing of Low- Cost Oxygen Concentrator"

is a bonafide record of project work done by

Kaustubh Sonukale (41247)

This project is approved for the award of degree of

B. Tech. in Mechanical Engineering of Dr. Babasaheb Ambedkar Technological University, Lonere.

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Kaustubh Sonukale (41247)

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1. INTRODUCTION

Oxygen is an essential medicine required at all levels of the health care system; only high quality, medical-grade oxygen should be given to patients. Pressure swing adsorption (PSA) oxygen generating plants are a source of medical-grade oxygen.

Oxygen concentrators are a suitable and favorable option for administering point-of-care oxygen in developing-country settings, especially where cylinders and piped systems are inappropriate or unavailable. Even where oxygen supplies are available at health facilities, patient access may be limited due to missing accessories, inadequate electricity and a shortage of trained staff.

Oxygen concentrators provide a sustainable and cost-effective source of medical oxygen to health facilities with reliable power. An oxygen concentrator is a medical device that draws in air from the environment and passes it through molecular sieve beds to concentrate room oxygen to therapeutic levels for delivery to the patient. Oxygen therapy for the treatment of hypoxemia involves the delivery of concentrated oxygen to the patient to improve and stabilize blood oxygen saturation levels. It is critical to understand the indications and clinical use for oxygen.[1]

Figure 1: OxyCon

AIR SEPARATION PROCESSES

The primary products of air separation, O2, N2 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:

A. CRYOGENIC AIR SEPARATION PROCESSES

Pure gases can be separated from air by first cooling it until it liquefies, then selectively distilling the components at their various boiling temperatures. The process can produce high purity gases but is energy-intensive. This process was pioneered by Carl von Linde in the early 20th century and is still used today to produce high purity gases.

The cryogenic separation process requires a very tight integration of heat exchangers and separation columns to obtain a good efficiency and all the energy for refrigeration is provided by the compression of the air at the inlet of the unit.

To achieve the low distillation temperatures, an air separation unit requires a refrigeration cycle that operates by means of the Joule–Thomson effect, and the cold equipment has to be kept within an insulated enclosure (commonly called a "cold box"). The cooling of the gases requires a large amount of energy to make this refrigeration cycle work and is delivered by an air compressor.[1]

B. NON-CRYOGENIC AIR SEPARATION PROCESSES

1. MEMBRANE BASED SEPARATION

Gas separation across a membrane is a pressure-driven process, where the driving force is the difference in pressure between inlet of raw material and outlet of product. The membrane used in the process is a generally non-porous layer, so there will not be a severe leakage of gas through the membrane. The performance of the membrane depends on permeability and selectivity. Permeability is affected by the penetrant size. Larger gas molecules have a lower diffusion coefficient. The polymer chain flexibility and free volume in the polymer of the membrane material influence the diffusion coefficient, as the space within the permeable membrane must be large enough for the gas molecules to diffuse across.

The membrane gas separation equipment typically pumps gas into the membrane module and the targeted gases are separated based on difference in diffusivity and solubility. For example, oxygen will be separated from the ambient air and collected at the upstream side, and nitrogen at the downstream side.[1]

2. ADSORPTION BASED SEPARATION

Adsorption process technology is based on the ability of some natural and synthetic materials to preferentially adsorb either nitrogen or oxygen. This technology is used to produce either nitrogen or oxygen by passing compressed air at several atmospheric pressures through a vessel containing adsorbent materials. Adsorbents are chosen on the basis of their adsorption characteristics. Special adsorptive materials are used as a molecular sieve, preferentially adsorbing the target gas species. A desirable adsorbent has much greater affinity for non-product molecules than for the product gas (nitrogen or oxygen). This characteristic results in most of the molecules of the product gas passing through the bed and into the product stream, while other components of the air are captured by the adsorbent.[2]

2.1 PRESSURE SWING ADSORPTION

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 cycle consists of two adsorption columns packed with zeolite adsorbent particles and has four steps: pressurization, adsorption, blowdown, and purge.[2]

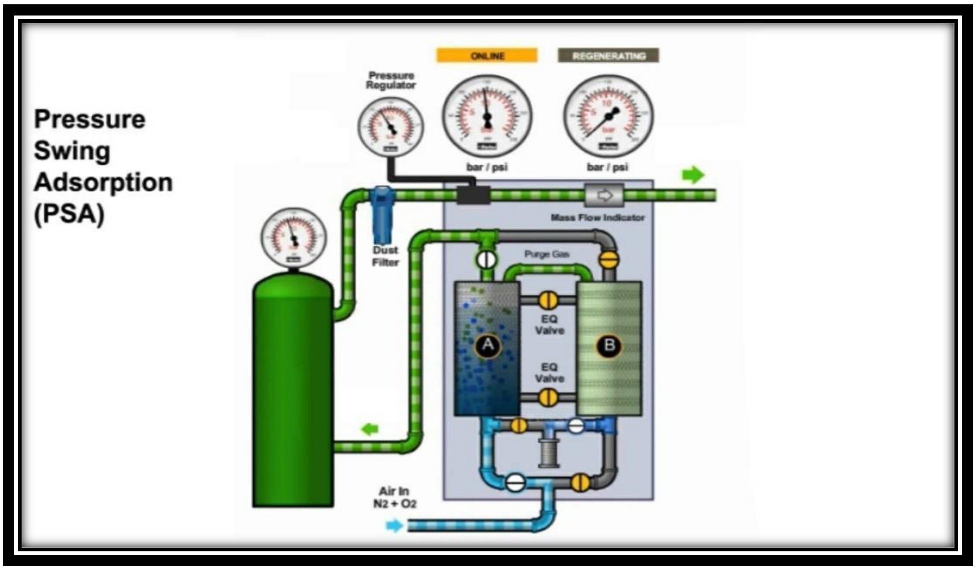


Figure 2: PSA

2.2VACUUM-PRESSURE SWING ADSORPTION

Vacuum-pressure swing adsorption processes are a special class of noncryogenic pressure swing adsorption-based air separation technology in which the adsorption step is carried out at atmospheric pressure in case of VSA and just above atmospheric pressure in the VPSA or PVSA processes and desorption is under vacuum using zeolite molecular sieve adsorbent materials for selective adsorption of nitrogen. The VSA and VPSA processes separate oxygen and nitrogen from air at near ambient pressure and temperature where the working capacity of these processes is much higher than PSA processes for the same pressure range.[2]

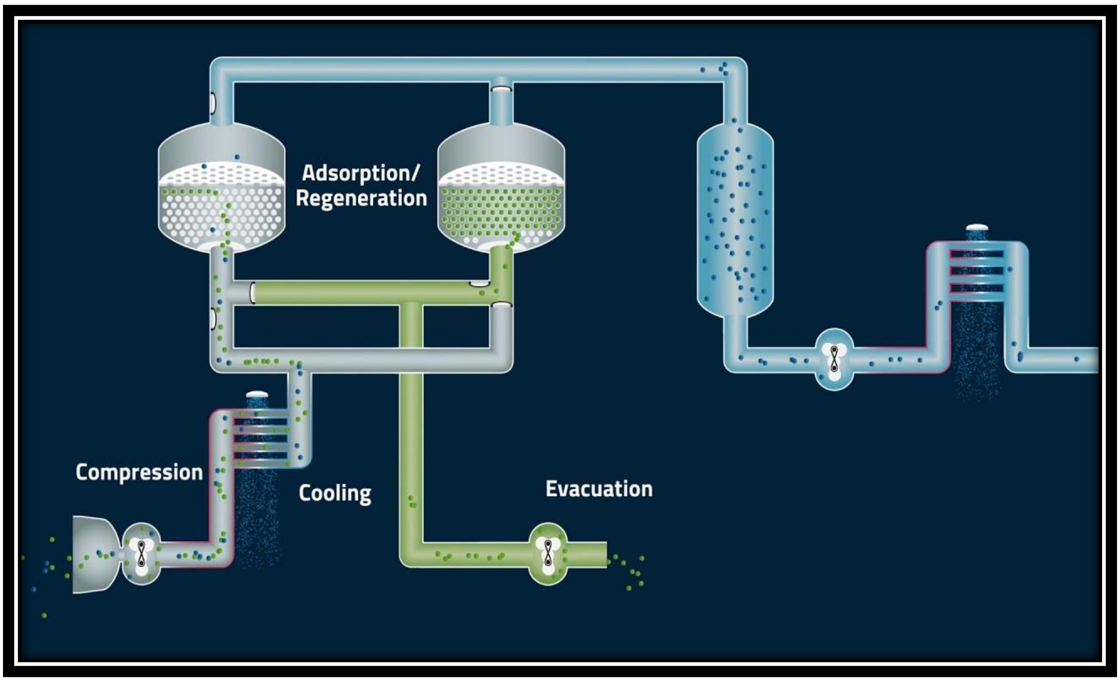


Figure 3: VPSA

2. LITERATURE REVIEW

After reading multiple research papers we have found out that most commonly used processes for enriching oxygen from atmospheric air is done by 2 processes namely PSA (Pressure Swing Adsorption) and VPSA (Vapour Pressure Swing Adsorption). A few research papers also concluded that membrane-based separation also holds potential for providing medical grade oxygen. Temperature swing adsorption (TSA) is also an up-and-coming experimental procedure for enriching oxygen, this process utilizes the temperature aspect for blocking nitrogen and allowing smooth passage for oxygen and ultimately provides medical grade oxygen.

PSA is largely used for household application and single end user application, basically it can be used for all small-scale purposes. VPSA is largely used for industrial purposes and large-scale production of oxygen. Hospitals with inbuild oxygen concentrators mainly relay on PSA based oxygen enrichment processes.

Using multiple zeolite bed, the overall efficiency of enrichment can be increased but it is ultimately capped at 97% to 98%. Zeolite 13X and 5A are the mostly preferred for oxygen concentration.

A few of the Chinese companies are providing/manufacturing lithium + cation inserted in zeolite 13X and 5A respectively which greatly increases the nitrogen adsorption potential. Desiccants like silica gel are used to reduce the moisture content in supplied air.

Some research papers also conclude that giving a direct atmospheric connection to the saturated zeolite canisters can help in purging process.

By using various electronically actuated solenoid valves the flow of oxygen/air can be diverted at various junctions effectively.

I. Stationary Oxygen Concentrators:

Most stationary oxygen concentrators weigh less than 27 kg and have wheels so that they are easily movable by the user. They are self-contained devices that supply an economical, continuous stream of oxygen at flow rates up to 10 liters per minute (LPM). Very low flows, down to 0.1 LPM, may be delivered via the built-in flowmeter or with additional accessories. Most concentrators that are appropriate for health facilities can deliver at least 5 LPM and operate on alternating current electricity, and consume approximately 280 - 600 watts (W), depending on the model (Refer below table). Separate models for 110 - 120 VAC (typically 60 Hz) and 220 - 240 VAC (typically 50 Hz) is generally available from the manufacturer to match the voltage and frequency of the local grid power. [2]

II. Portable Oxygen Concentrators:

Portable oxygen concentrators have a lower output capacity (3 LPM or less), consume less power than their stationary counterparts (approximately 40 - 130 W) and are used by individual patients as ambulatory oxygen systems. They may contain batteries capable of operating on direct current (DC). [2]

Concentrators are designed for continuous operation and can produce oxygen 24 hours per day, 7 days per week, for up to 5 years or more. These devices can be used at any level of health facility. But not used in highly specialized care units such as ICUs, where centralized oxygen supply is preferred. They are highly applicable in situations which require home based supplementation is indicated such as COPD, Sleep Apnea etc. For these there is a need for continuous source of reliable power and a system for regular cleaning and maintenance by users and technical personnel alike. While most oxygen concentrators operate by the same principles, spare parts are not interchangeable between different models. [2]

3. PROBLEM STATEMENT & OBJECTIVES

3.1 PROBLEM STATEMENT

We have developed a low-cost oxygen concentrator. As its primary goal, this project will further enhance the capabilities of the Oxygen Concentrator. Among the proposed improvements are improving the efficiency to over 90% i.e., Medical Graded Efficiency, reduction of the external forced frequency of the compressor, making the assembly more compact by optimizing placement of component.

3.2 OBJECTIVES

Objectives of this Project are as follows:

1. Identifying ways to improve the oxygen concentrator’s efficiency
2. Enhancing oxygen concentrator cooling abilities
3. Study the design of Aesthetics of existing model and improve the Aesthetic of project.
4. Study the Ergonomics, Sound-Acoustic and Reduce vibration produced in the project.

4. METHODOLOGY

4.1 COMPONENTS

ZEOLITE 5A

Molecular sieve 5A, also called zeolite 5A or zeolite 5A, is one type of aluminosilicate crystal with average pores measuring of 5 angstrom (0.5 nm). Molecular with kinetic diameter larger than 5 angstroms will be adsorbed by zeolite 5A, otherwise be excluded.

Zeolite 5A molecular sieves are typically used for normal- and iso-paraffins separation, removing water, carbon dioxide, hydrogen sulfide from sour natural gas, while decreasing COS formation.

GROSS PARTICLE FILTER / INTAKE FILTER

The Air Intake Filter traps dust and particles from entering the stationary oxygen concentrator as ambient air is drawn into the unit.

COMPRESSOR

A compressor is a device that increases the pressure of a substance (usually a gas) by reducing the volume of the substance.

WATER TRAP

It is used to trap the water vapour / moisture from the compressed air from the compressor.

HEAT EXCHANGER

A heat exchanger is a system used to transfer heat between two or more fluids. Heat exchangers are used in both cooling and heating processes. The fluids may be separated by a solid wall to prevent mixing or they may be in direct contact.

SOLENOID VALVES

Solenoid valves are control units which, when electrically energized or de-energized, either shut off or allow fluid flow. The actuator takes the form of an electromagnet. When energized, a magnetic field builds up which pulls a plunger or pivoted armature against the action of a spring.

ZEOLITE CANISTER

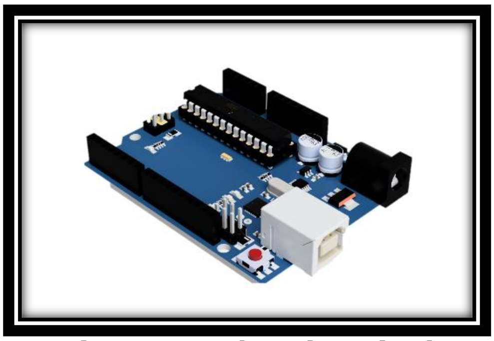
Canister is a container which is roughly cylindrical in shape and holds pressurized gas in it. A zeolite canister is a canister which is filled with zeolite particles which are used in adsorption of Nitrogen from air and thus to separate oxygen form it.

PRODUCT TANK

It is a canister used to store the oxygen enriched air from the Concentration process and also acts as a temporary storage reservoir in case of continuous supply.

PRESSURE REGULATOR

Air pressure regulators control the pressure in air lines used by pneumatic tools and machines. To provide consistent pressures, they remove fluctuations in the air supply and are adjustable. The reduction in pressure is the key characteristic of pressure regulators; outlet pressure is always less than the inlet pressure.



ELECTRONIC CIRCUIT

An electronic circuit is composed of individual electronic components, such as resistors, transistors, capacitors, inductors and diodes, connected by conductive wires or traces through which electric current can flow. This is used to actuate the solenoid valves used to control to the air supply to and from the canisters.

FLOW METER / REGULATOR

An air flow meter is a device that measures air flow, i.e., how much air is flowing through a tube and also control the mass of air flowing through it. It measures the mass of air flowing through the device per unit time.

Non-Return Valve

A non-return valve allows a medium to flow in only one direction and is fitted to ensure that the medium flows through a pipe in the right direction, where pressure conditions may otherwise cause reversed flow.

FAN

It is used to cool the air compressor.

Silica Gel

Silica gel is an amorphous and porous form of silicon dioxide, consisting of an irregular tridimensional framework of alternating silicon and oxygen atoms with nanometer-scale voids and pores. The voids may contain water or some other liquids, or may be filled by gas or vacuum.

Pipe

Air tubing pipe of 6mm diameter used to carry air form different components at high pressure upto 10 bars.

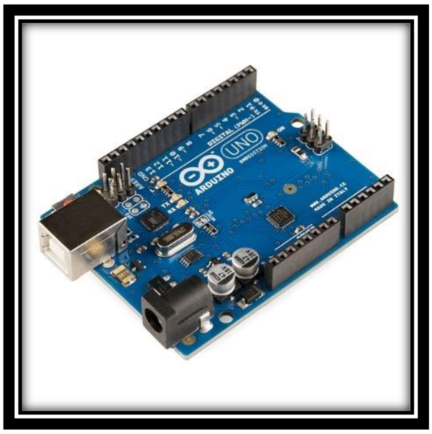
Compressor Filter

Air compressor filters, also called airline filters, are used in air lines as a way to stop liquids and solid contaminants from entering air compressors. They stop these contaminants from entering the equipment and causing damage.

Pneumatic Silencer

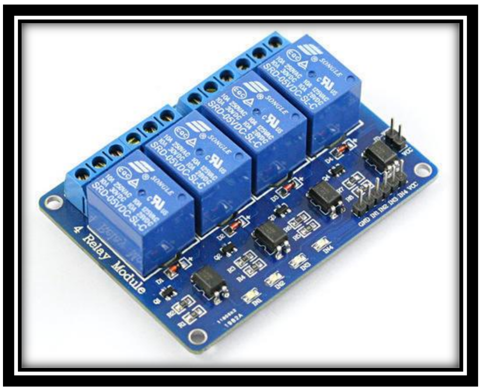
Pneumatic silencers are used in pneumatic systems to safely vent pressurized air to the atmosphere. Also known as mufflers they are typically used with valves, manifolds, cylinders, compressors and fittings.

Arduino UNO R3



The Arduino Uno is an open-source microcontroller board developed by Arduino.cc. The board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits. The board has 14 digital I/O pins, 6 analog I/O pins, and is programmable with the Arduino IDE (Integrated Development Environment). It can be powered by the USB cable or by an external 9-volt battery, though it accepts voltages between 7 and 20 volts.

Relay Module



The relay module is an electrically operated switch that can be turned on or off deciding to let current flow through or not. They are designed to be controlled with low voltages like 3.3V or 5V from Arduino.

Pipe Fittings

Pneumatic fittings are parts used to connect sections of pipe, tube, and hose in pneumatic (pressurized gas) systems. Compared to hydraulic fittings, pneumatic fittings are typically characterized by tighter seals and lower pressure requirements.

4.2 WORKING PRINCIPLES

Working Principle of Solenoid Valve

A solenoid valve is an electrically controlled valve. The valve features a solenoid, which is an electric coil with a movable ferromagnetic core (plunger) in its center. In the rest position, the plunger closes off a small orifice. An electric current through the coil creates a magnetic field. The magnetic field exerts an upwards force on the plunger opening the orifice. This is the basic principle that is used to open and close solenoid valves.

A solenoid valve consists of two main components: a solenoid and a valve body (G). Figure 2 shows the components. A solenoid has an electromagnetically inductive coil (A) around an iron core at the centre called the plunger (E). At rest, it can be normally open (NO) or normally closed (NC). In the de-energized state, a normally open valve is open and a normally closed valve is closed. When current flows through the solenoid, the coil is energized and creates a magnetic field. This creates a magnetic attraction with the plunger, moving it and overcoming the spring (D) force. If the valve is normally closed, the plunger is lifted so that the seal (F) opens the orifice and allows the flow of the media through the valve. If the valve is normally open, the plunger moves downward so that the seal (F) blocks the orifice and stops the flow of the media through the valve. The shading ring (C) prevents vibration and humming in AC coils.

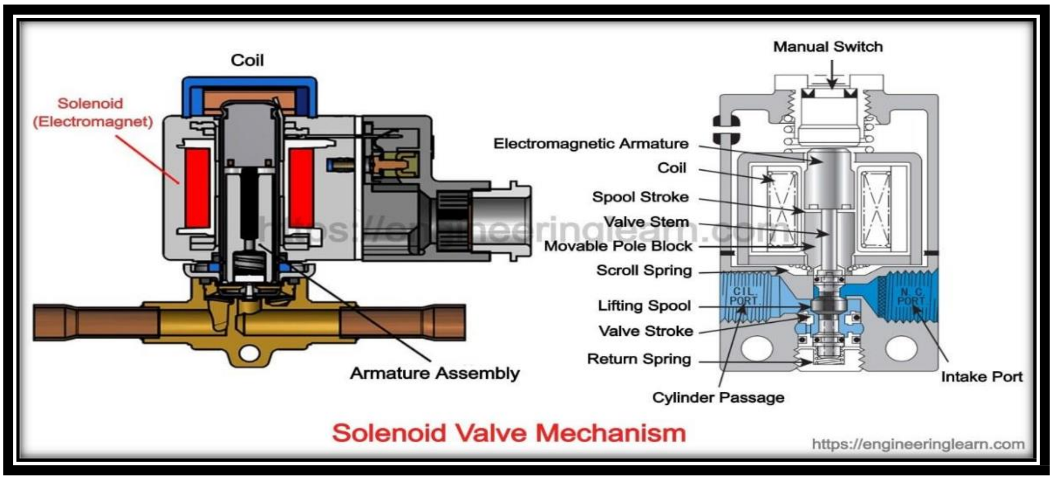


Figure 4: Solenoid Valve Mechanism

Solenoid valves are used to close, open, dose, distribute or mix the flow of gas or liquid in a pipe. The specific purpose of a solenoid valve is expressed by its circuit function. An overview of 2-way and 3-way solenoid valves is below. For an in-depth understanding of symbols and understanding circuit function diagrams, view our valve symbol page.

1. 2-way solenoid valve

A 2-way solenoid valve has two ports, an inlet and an outlet. Flow direction is critical to ensure proper operation, so there is typically an arrow indicating the flow direction. A 2-way valve is used to open or close the orifice. Figure 3 shows an example of a 2-way solenoid valve.

3-way solenoid valve

A 3-way valve has three connection ports. Typically, it has 2 states (positions) it can be in. So, it switches between two different circuits. A 3-way valve is used to open, close, distribute, or mix media. Figure 4 shows an example of a 3-way solenoid valve. [33]

Working Principle of Oil Free Air Compressor

Oil-free air compressors either have no mechanical contact inside the compression chamber or use alternate materials to protect the mechanism without lubrication.

Most oil-free compressors utilize other materials like water or a Teflon coating to keep the mechanism running smoothly. Because the lubrication of bearings and gears is all external to the compression chamber, proper sealing prevents any oil from contaminating the compressed air. The result is a 100% oil-free air supply. Some oil-free designs have even removed metal-to-metal contact within the compression chamber, eliminating the need for oil-based and synthetic lubrication altogether.

These purity and environmental benefits will often translate into other savings that may reduce your overall ownership costs. Here are a few things to consider if you're contemplating switching to an oil-free model: There's no need to collect or dispose of oil- ladened condensate.

1. Downstream filters have reduced replacement needs, because they're not filtering oil.

2. Energy costs are minimized because there’s no need to increase force -- some fluid- flooded units can see a downstream pressure drop due to filtration.

3. Reduced oil costs, because there’s no need to continually refill your compressor.

4. Typically, these units can unload within two seconds of the unload command and will use about 18% of their full load horsepower when unloaded.

Working of Oxygen Concentrator

An oxygen concentrator is a medical device that provides supplemental or extra oxygen to a patient with breathing issues. The device consists of a compressor, sieve bed filter, oxygen tank, pressure valve, and a nasal cannula (or oxygen mask). Like an oxygen cylinder or tank, a concentrator supplies oxygen to a patient via a mask or nasal tubes. However, unlike oxygen cylinders, a concentrator doesn’t require refilling and can provide oxygen 24 hours a day. A typical oxygen concentrator can supply between 5 to 10 liters per minute (LPM) of pure oxygen. [16]

The 5 Step Concentrator Process:[18]

1. Takes air from the room.
2. Compresses the oxygen.
3. Takes out nitrogen from the air.
4. Adjusts the way the air is delivered.
5. Delivers the purified air.

An oxygen concentrator works by filtering and concentrating oxygen molecules from the ambient air to provide patients with 90% to 95% pure oxygen. The compressor of the oxygen concentrator sucks ambient air and adjusts the pressure at which it is provided. The sieve bed made of a crystalline material called Zeolite separates the nitrogen from the air. It takes regular air and purifies it to 90-95% oxygen. To do this, the concentrator uses a compressor that moves air into sieve bed filters to remove the nitrogen. It then distributes the purified oxygen through hoses inserted into the nostrils. The nitrogen is later released back into the air. A concentrator has two sieve beds that work to both release oxygen into a cylinder as well as discharge the separated nitrogen back into the air. This forms a continuous loop that keeps producing pure oxygen.

4.3MANUFACTURING PROCESS:

Drilling

Drilling is a cutting process that uses a drill bit to cut a hole of circular cross-section in solid materials. The drill bit is usually a rotary cutting tool, often multi-point.

The bit is pressed against the work-piece and rotated at rates from hundreds to thousands of revolutions per minute.

This forces the cutting edge against the work-piece, cutting off chips (swarf) from the hole as it is drilled.

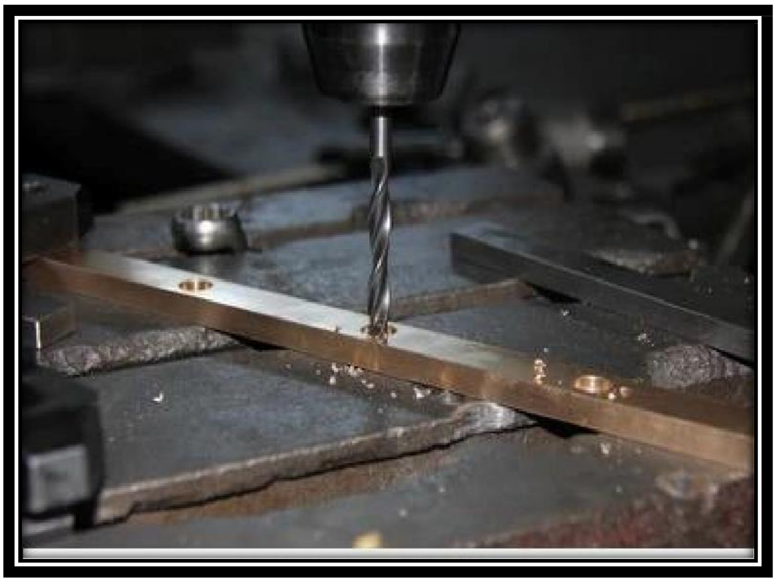


Figure 5: Drilling

Boring

- Boring is a machining process uses a specially designed cutting tool like a drill bit to enlarge a hole that is already in the part to improve the accuracy.
- The cutting removes material from the internal of the work piece.
- Boring has a wide range of applications it can machine holes of different sizes and different precision grades.
- For holes with large diameter, high precision of size and location, boring is almost the only processing method.
- Boring on the lathe can be completed through mounting the holder and boring tool bar with cutter bit on the tool post and revolving the part.

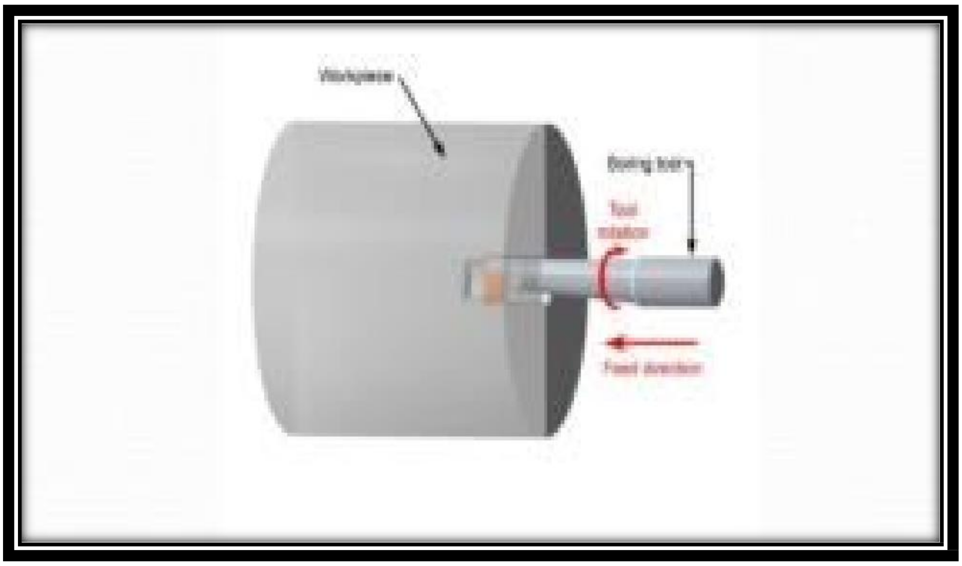


Figure 6: Boring

Cutting.

- Cutting is a technique where the operator moves a material (workpiece) such as metal and the tool in relation to each other in order to shape the workpiece into the desired form through shaving, drilling, etc.
- Cutting can be broadly divided into two methods: rolling, where the workpiece is restrained while the tools turn, and turning, where the workpiece is turned instead.

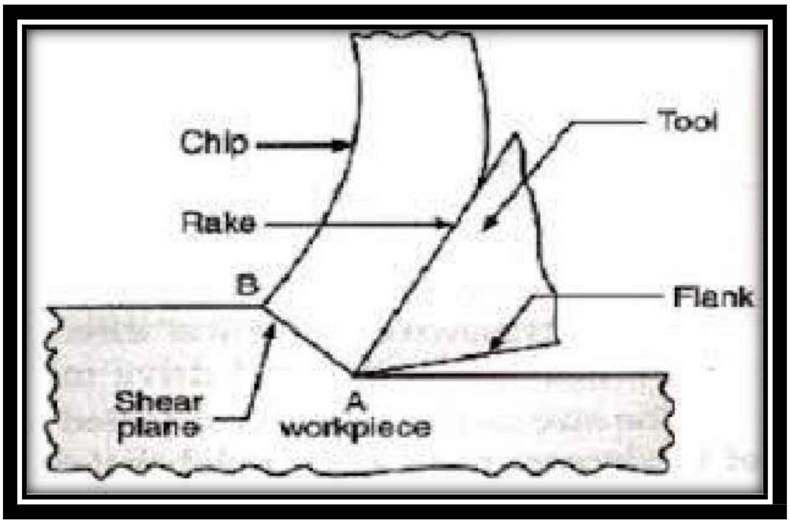


Figure 7: Cutting

Bending

- Bending is a manufacturing process that produces a V-shape, U-shape, or channel shape along a straight axis in ductile materials, most commonly sheet metal.
- Commonly used equipment include box and pan brakes, brake presses, and other specialized machine presses.
- With the help of bending, we have manufactured the heat exchanger pipe.

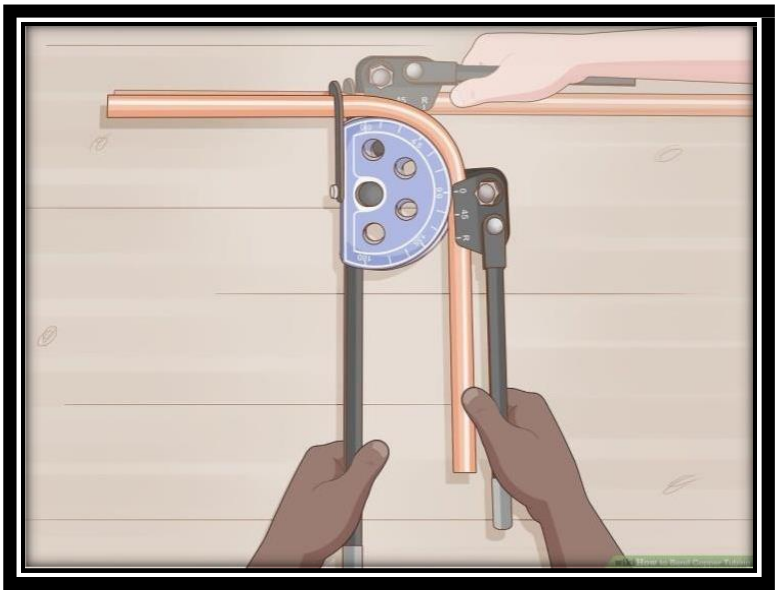


Figure 8: Bending

Fitting.

Fitting means preparing matching parts to touch or join each other in such a way that one will turn inside of another and will slide upon another, or the part hold tightly together.

Figure 9: Fitting

Soldering

- Soldering is a joining process used to join different types of metals together by melting solder.
- Solder is a metal alloy usually made of tin and lead which is melted using a hot iron.
- The iron is heated to temperatures above 600 degrees Fahrenheit which then cools to create a strong electrical bond.

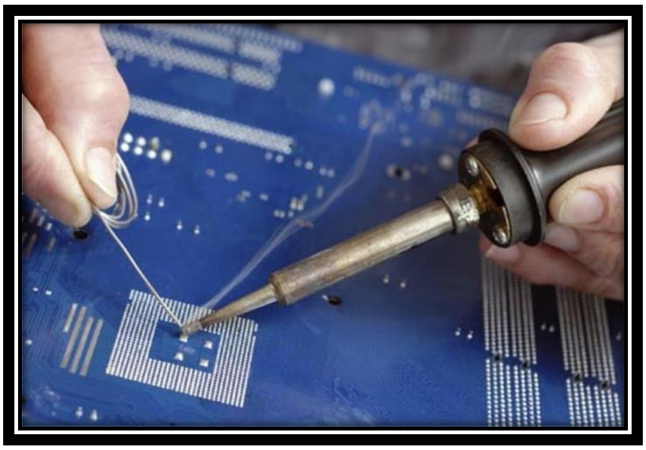


Figure 10: Soldering

4.4 CALCULATIONS

Air Conditions				
Gases	**In**	**Out**	**% Air in tank**	**% Gas Retained**
O2	21.00%	21.00%	91.30%	0.00%
N2	79.00%	2.00%	8.70%	97.47%
	100.00%	23.00%	100.00%	
Pressure				
Bar	**Atm**	**PSI**	**outlet Pressure of Compressor**	
4	3.947693067	58.0152	4.053	bar
4.053	4	58.7836	405300	
6.894744825	6.804618975	100		
Dimensions				
dp (Pipe)	6	mm	0.006	m
dc (Canister)	40	mm	0.04	m
dt (Tank)	40	mm	0.04	m
Lc (Canister)	500	mm	0.5	m
Lt (Tank)	300	mm	0.3	m
ds(zeolite)	3	mm	0.003	m
Rs(zeolite)	1.5	mm	0.0015	m
In Flow Volume				
60	lit/min	0.001	m^3/s	1000
cycle time				
30	sec			

Pi	3.142857143	
Ap	2.82857E-05	m^2
Ac	0.001257143	m^2
vel_p	35.35353535	m/s
vel_c	0.795454545	m/s
Head loss	5.215	m of water
	0.51140376	bar
Inlet Pressure in Zeolite	0.1	bar
Pz	3.44159624	bar
Canister Volume		
Vc(can)	0.000628571	m^3
Tank volume		
Vt	0.000377143	m^3
Canister Pressure		
Pc	8.413214755	bar
pressure after no of cycles		
Pct	252.3964427	bar

22% of flow in volume		
22%Fin	0.00022	m^3
Time to fill tank		
VtFillTime	1.714285714	sec

Zeolite balls			
Vz(zeolite)	1.41429E-08	m^3	m^3
Vcube	0.000000027	m^3	m^3
		volume	m^3
no of cubes	23280.42328	0.000628571	m^3
no of balls	23280.42328	0.000329252	m^3
1/3rd of ball volume		0.000109751	m^3
Space between Balls and Cubes	0.00029932	m^3	
Total free space Volume	0.00040907	m^3	
Pressure in tank			
Pt	4.907708607	bar	
pressure after no of cycles			
30	147.2312582	bar	
Flow Rate in Tank			
Ft	13.2	lit/min	

Zeolite density			
ro	680	kg/m^3	
Weight	2.196372245	kg	
	2196.372245	g	
Porosity	0.4363		
bulk-solid	0.00029932	m^3	
	6.17053E-09	0.000299326	
Void_F (void fraction)			
=volume of voides/total volume of region			
0.476190476			
alpha	1.4876E-10		
C	5659.5		
Viscous Resistance		=1/alpha	6722222222
Inertial Resistance		=C	5659.5
vol of porous ball			
7.97233E-09			
0.295271429			

Pressure Drop in Zeolite Canister

Carman-Kozeny eq [22]

$$\Delta p = \frac{150L\mu}{{\Phi_s}^2 {D_p}^2} \frac{(1-\varepsilon)^2}{\varepsilon^3} \nu_s$$

Ergun eq (Laminar + Turbulent)

$$\Delta p = \frac{150L\mu}{{D_p}^2} \frac{(1-\varepsilon)^2}{\varepsilon^3} \nu_s + \frac{1.75L\rho}{D_p} \frac{(1-\varepsilon)}{\varepsilon^3} {\nu_s}^2$$

where,

- Δp is the pressure drop;
- L is the total height of the bed;
- ν_s is the superficial or "empty-tower" velocity;
- μ is the viscosity of the fluid;
- ε is the porosity of the bed;
- Φ_s is the sphericity of the particles in the packed bed;
- ρ is the density of the fluid. [19]

Density(kg/m^3)	**Diameter (m)**	**Velocity (m/s)**	**µ Dynamic Viscosity**	**Reynolds no**	**Flow**	**Length of Porous Bed (m)**	**Superficial velocity (m/s)**
1.225000	0.020000	1.060606	0.000018	1405.346051	Laminar	0.200000	1.060000
1.225000	0.085000	1.060600	0.000018	5972.686587	Turbulent	0.200000	1.060600
Sphericity	**Diameter of particle (m)**	**porosity**	**Void Factor**	**Carman-Kozeny (pressure drop laminar)**	**Ergun eq (laminar)**	**Ergun eq (Turbulent)**	**Ergun eq (Laminar + Turbulent)**
0.934000	0.003000	0.436300	0.704729	286.528747	249.955071	NA	NA
0.934000	0.003000	0.436300	0.704729	286.690933	250.096555	1091.135083	1341.231638

Viscous and Inertial Resistance of Zeolite Particles

Diameter in mm	Materials	zeolite ball diameter (m)	volume of solid ball (m^3)	Porosity	volume of porous ball (m^3)	bulk volume (m^3)	space occupied by gas (m^3)	Void Fraction	Permeability	Viscous Resistance	Inertial Resistance
3	zeolite 13x	0.003	1.4143E-08	0.4363	7.97233E-09	2.7E-08	1.9028E-08	0.704728571	2.40865E-07	4151699.985	984.2435495
0.6	Zeolite 2	0.0006	1.1314E-10	0.4363	6.37786E-11	2.16E-10	1.5222E-10	0.704728571	9.63461E-09	103792499.6	4921.217748
0.6	Zeolite	0.0006	1.1314E-10	0.4363	6.37786E-11	2.16E-10	1.5222E-10	0.704728571	9.63461E-09	103792499.6	4921.217748
	Diameter in mm	**Materials**	**zeolite ball diameter (m)**	**Particle Density (kg/m^3)**	**Bulk Density (kg/m^3)**	**Porosity**	**Void Fraction**	**Permeability**	**Viscous Resistance**	**Inertial Resistance**	
	3	Zeolite LiX	0.003	1066.5	790	0.25925926	0.35	6.08876E-09	164237123.4	17687.07483	
	0.6	Zeolite 2	0.0006	1066.5	790	0.25925926	0.35	2.4355E-10	4105928086	88435.37415	
	0.6	Zeolite	0.0006	1066.5	790	0.25925926	0.35	2.4355E-10	4105928086	88435.37415	

Heat Exchanger Length

$$\frac{Q}{L} = \frac{2\pi * (T_{in} - T_{out})}{\left(1/k_{conv}\right) + \frac{ln(r_{out}/r_{in})}{k_{cond}}}$$

R_Inner	0.004	m	**Mass Flow Rate (Air)**	0.0015	m3/s
R_Outer	0.005	m	**mdot**	0.0018375	
Temp_Inlet	500	degc	**Specific Heat Capapcity (cp)**	1.013	kj/kg.K
Temp_Ambient	27	degc	**Temp_Diff**	473	degC
Thermal Coefficient (k)	0.25	W/m.degC	**Q**	880.43805	Watt
Convection Coefficient (Air)	13.5	W/m.degC			
Q/L	3074.48605	Watts/m			
Q	3074.48605	Watt	**Lx**	0.2863692	m
Length (L)	1	m	**Qa**	880.43805	Watt

Spring Dimensions

OD		**Century Stock Number**	**Free Length**		**I. D.**		**Rate**		**Sugg. Max. Defl**	
Inches	**mm**		**Inches**	**mm**	**Inches**	**mm**	**Lbs./ In.**	**N/mm**	**Inches**	**mm**
0.625	**15.88**	**11445**	**1.5**	**38.1**	**0.435**	**11**	**157**	**28**	**0.39**	**9.8**
Sugg. Max. Load		**Solid Length**		**Wire Diameter**		**Total Coils**	**Material**	**Ends**	**Finish**	
Lbs.	**N**	**Inches**	**mm**	**Inches**	**mm**					
61	**270**	**0.67**	**16.9**	**0.095**	**2.4**	**7**	**Music Wire**	**Closed Ground**	**Zinc**	

4.5 SIMULATION CAE/CFD

CAE of Zeolite Canister (as per theoretical Calculations)

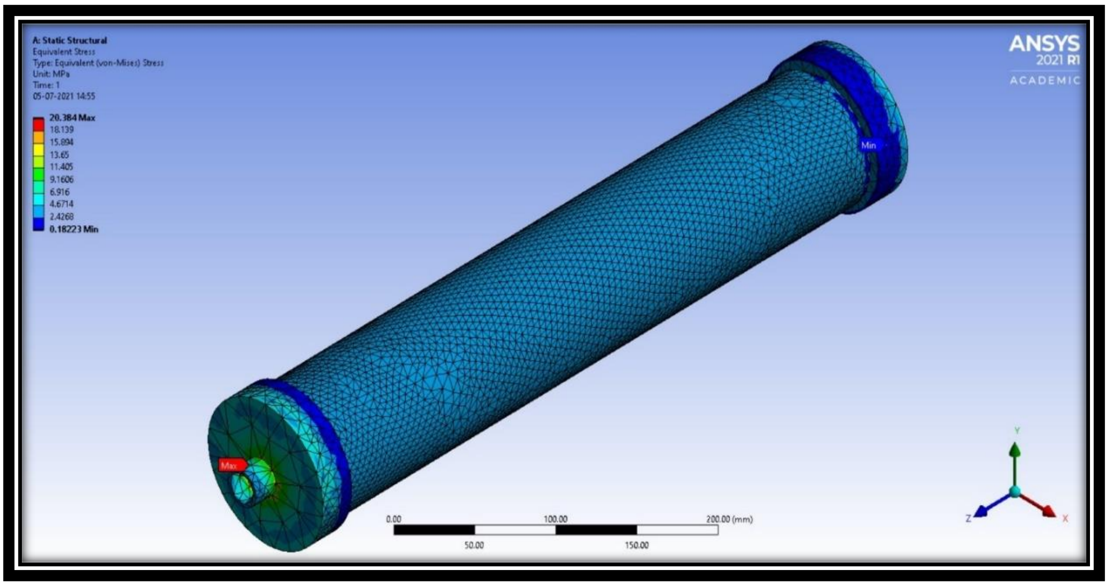


Figure 11: Von - Mises Stress (N/mm^2)

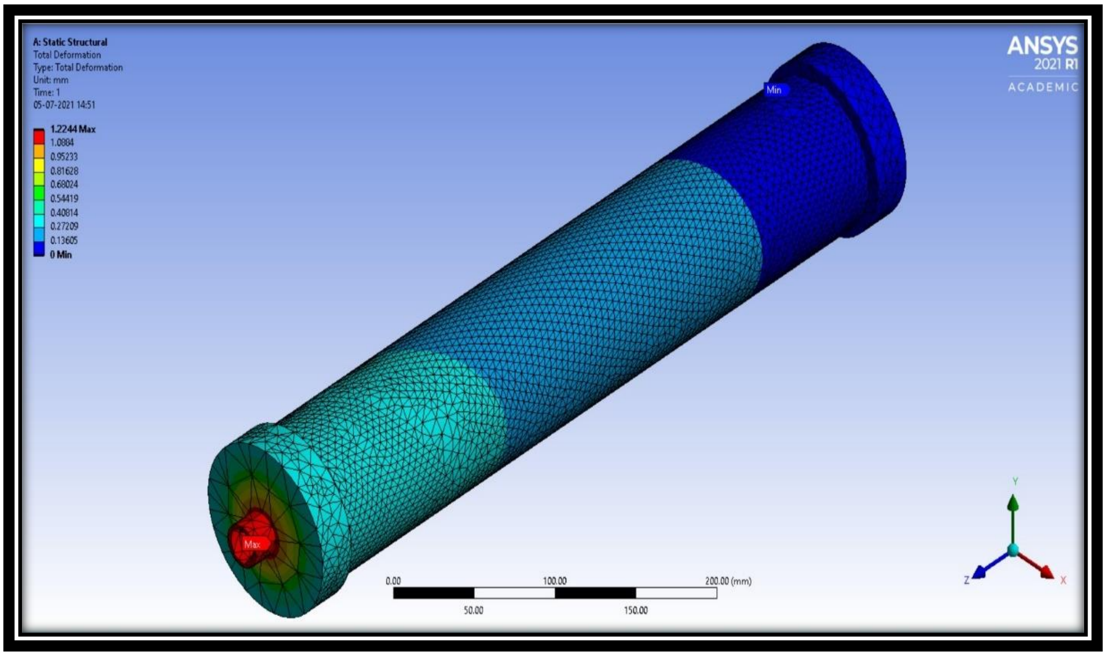


Figure 12: Deformation (mm)

CFD of Zeolite Canister (as per theoretical calculations)

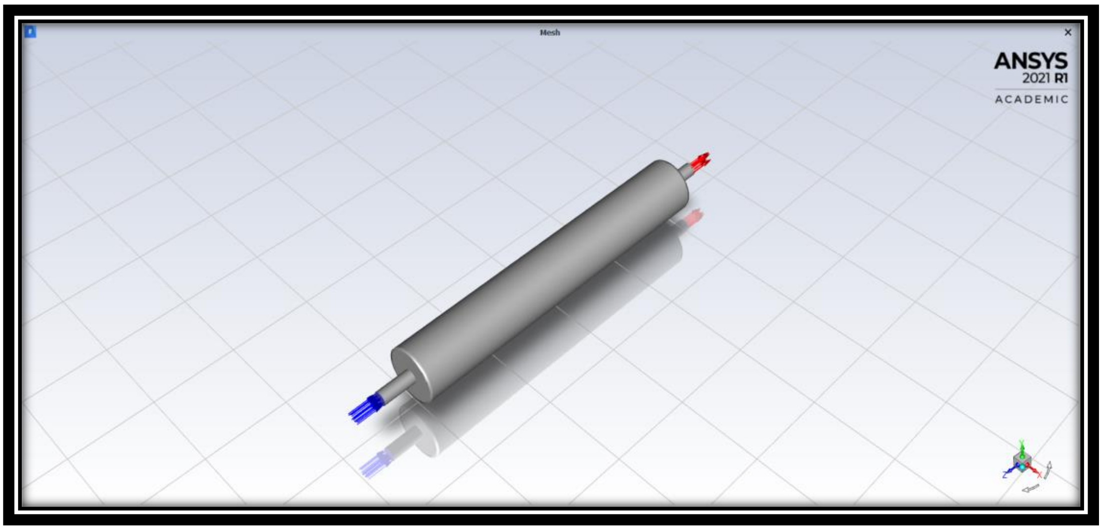


Figure 13:Velocity

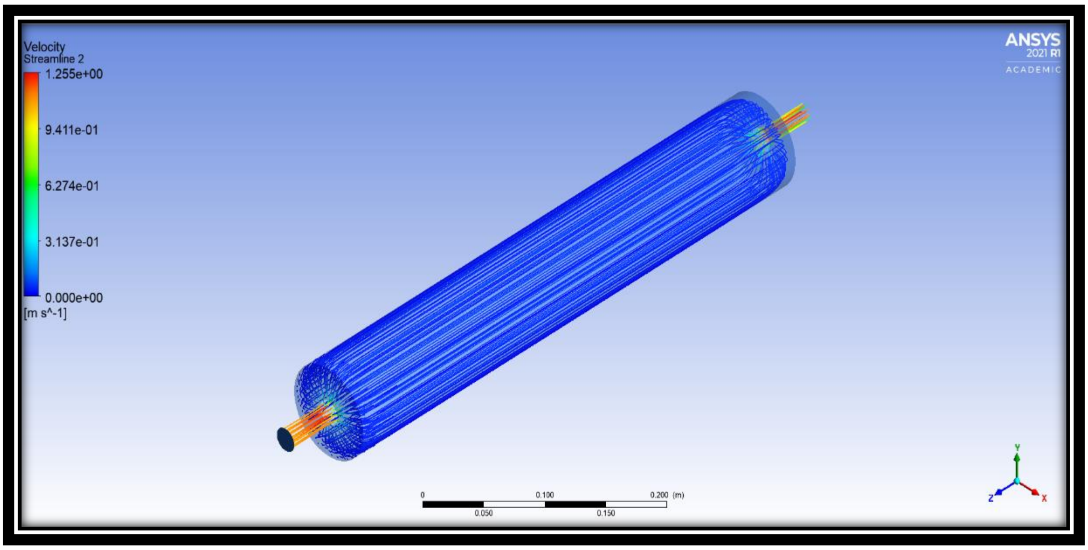


Figure 14: Velocity(m/s)

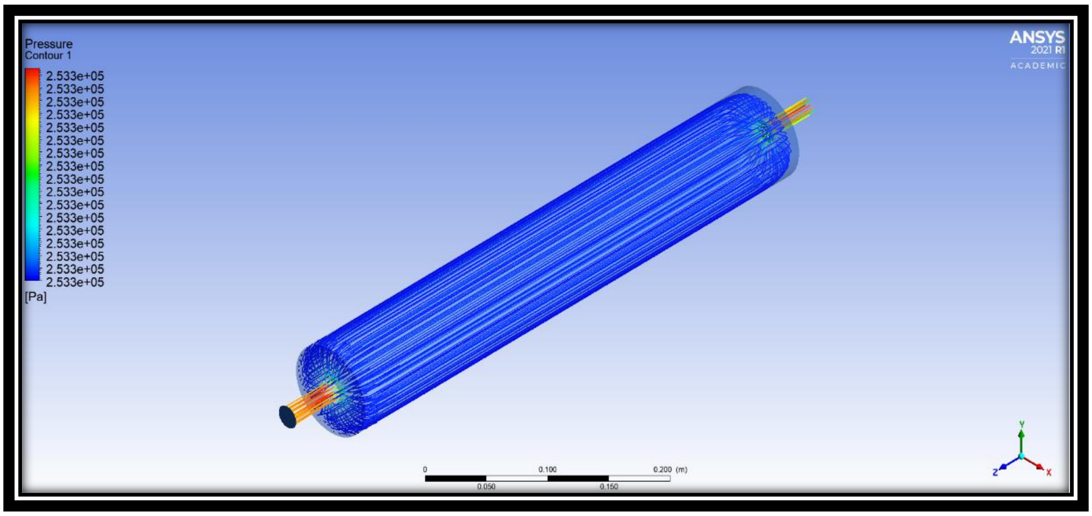


Figure 15: Pressure (N/mm^2)

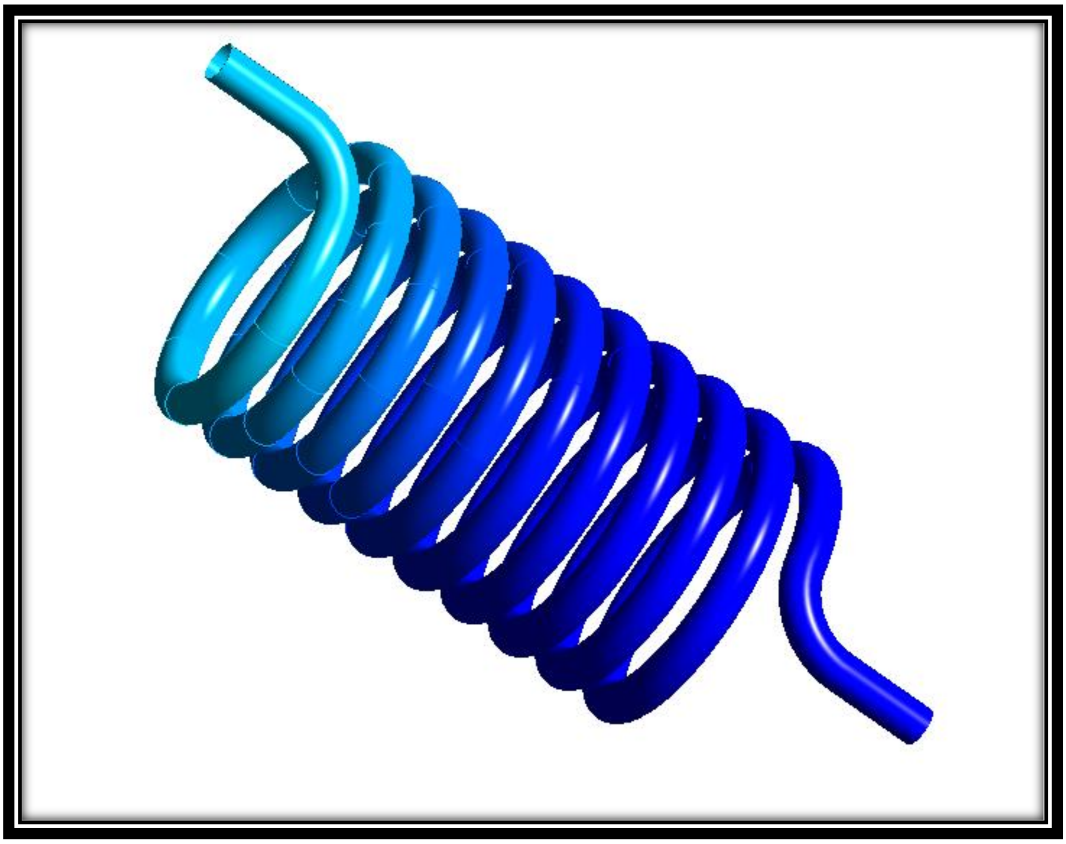


Figure 16: Heat Exchanger

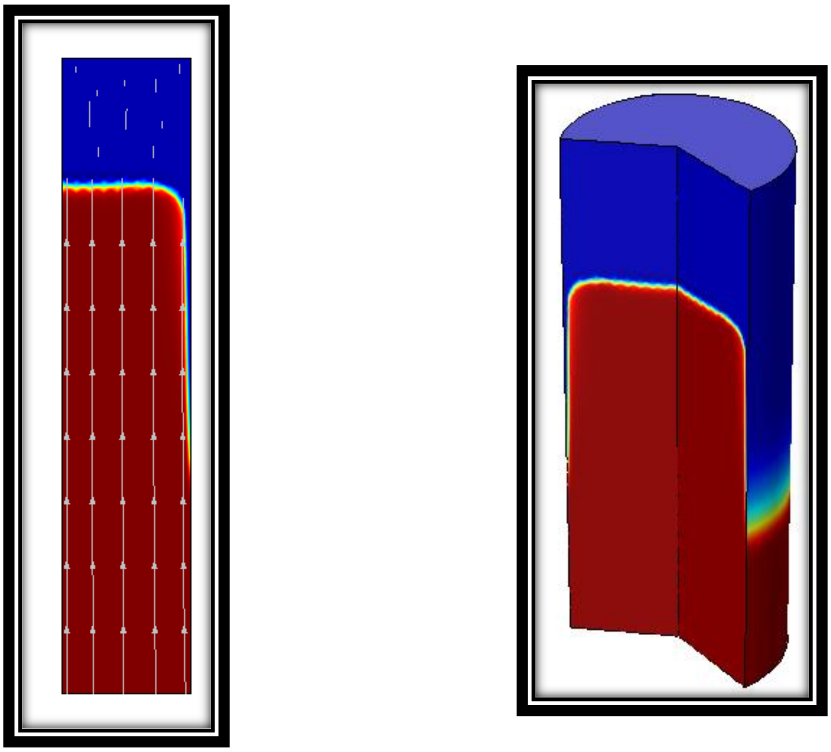


Figure 17: Adsorption @47s

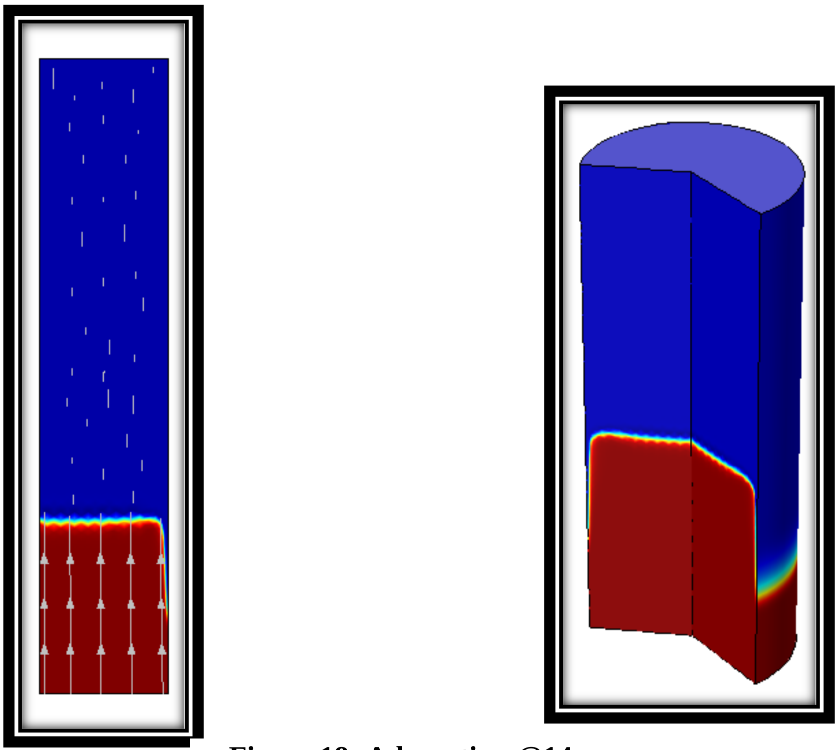


Figure 18: Adsorption @14s

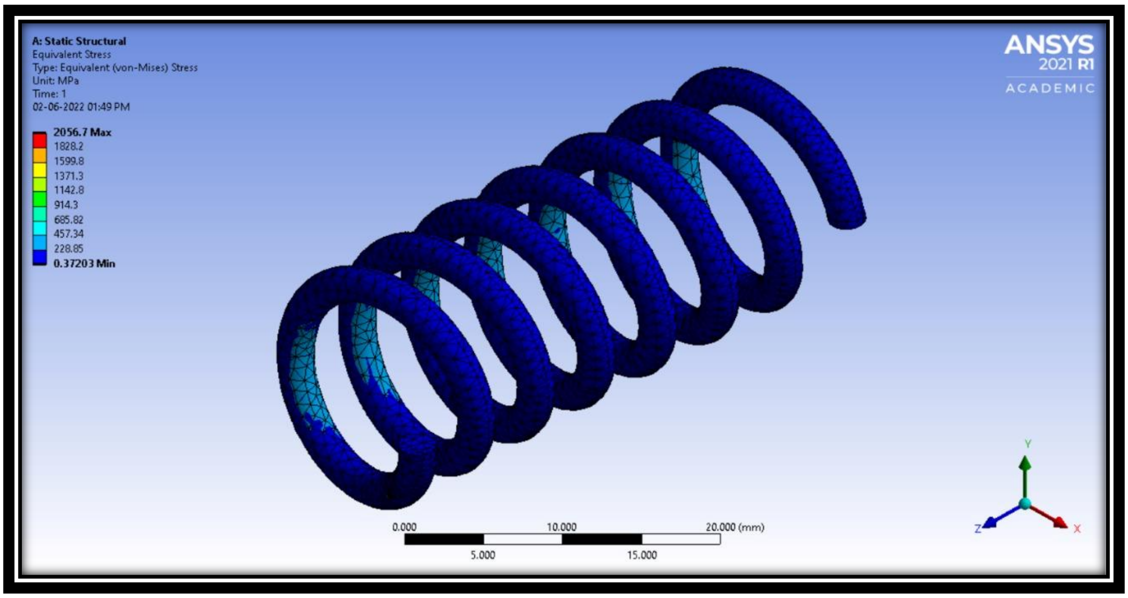


Figure 19: Spring - Equivalent Stress

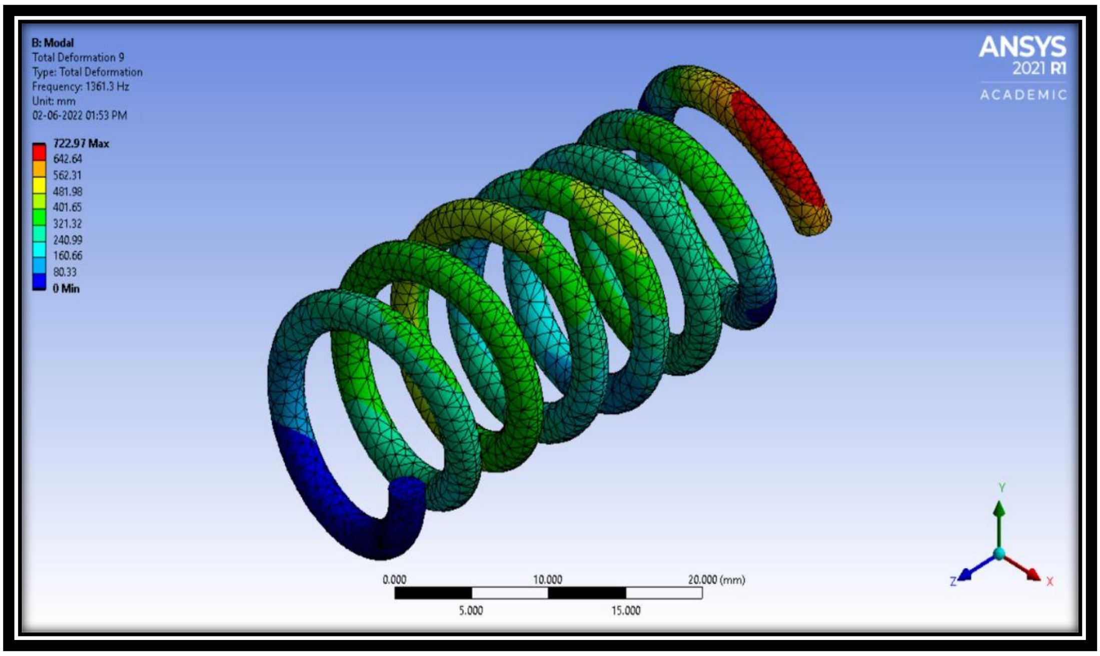


Figure 20: Spring - Total Deformation

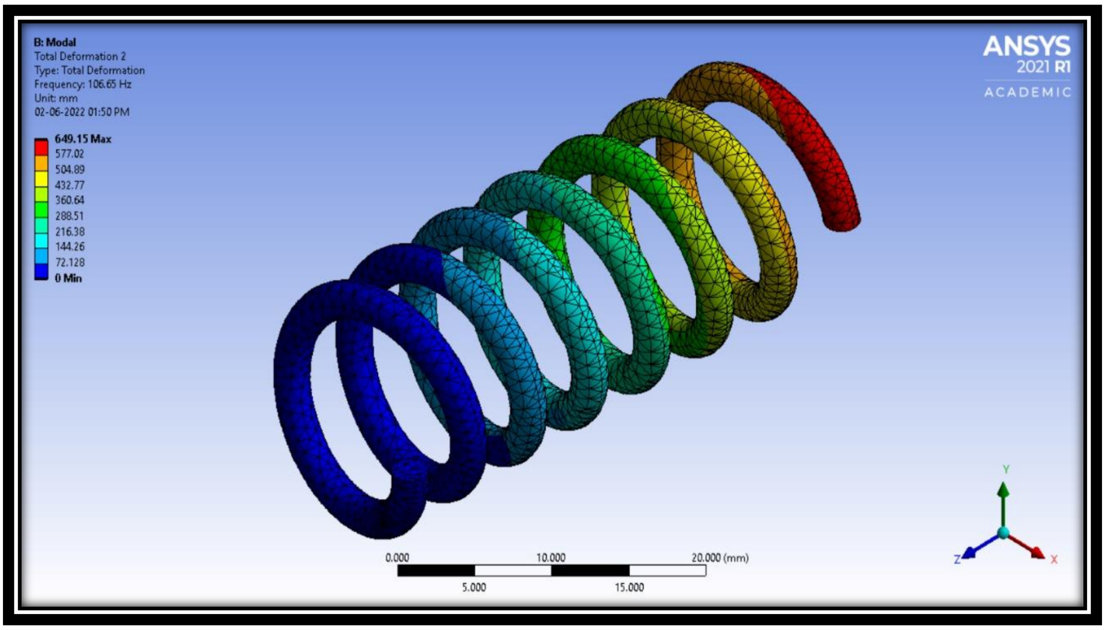


Figure 21: Spring - Total Deformation 2

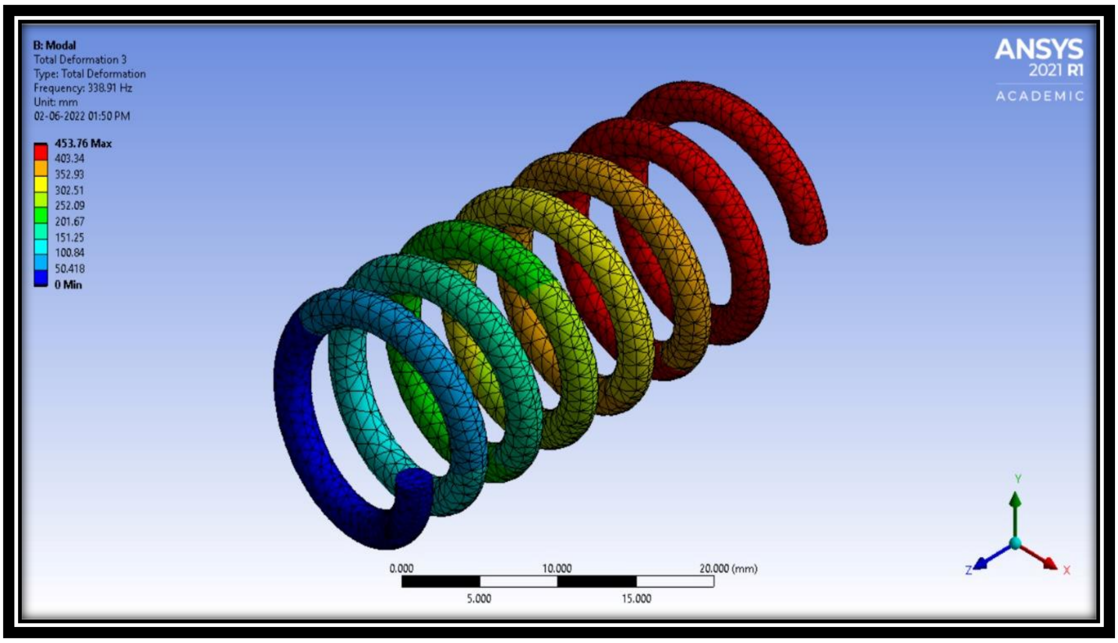


Figure 22: Spring - Total Deformation 3

4.6 CAD ASSEMBLY

Figure 23: Assembly 1

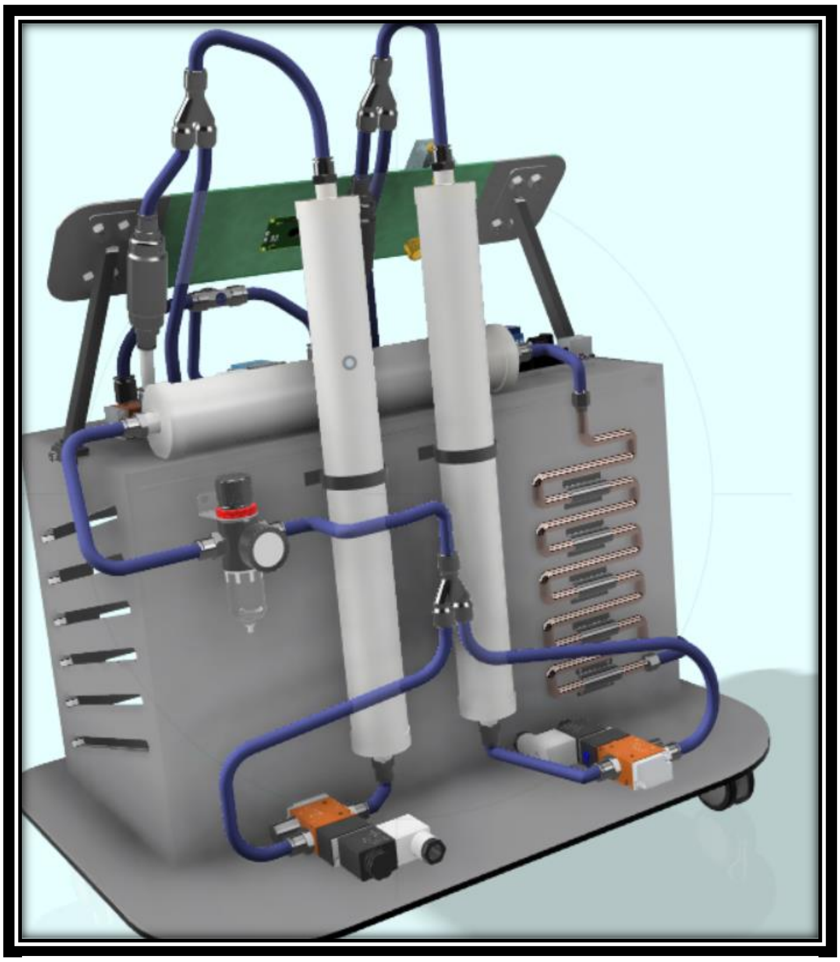


Figure 24:Assembly 2

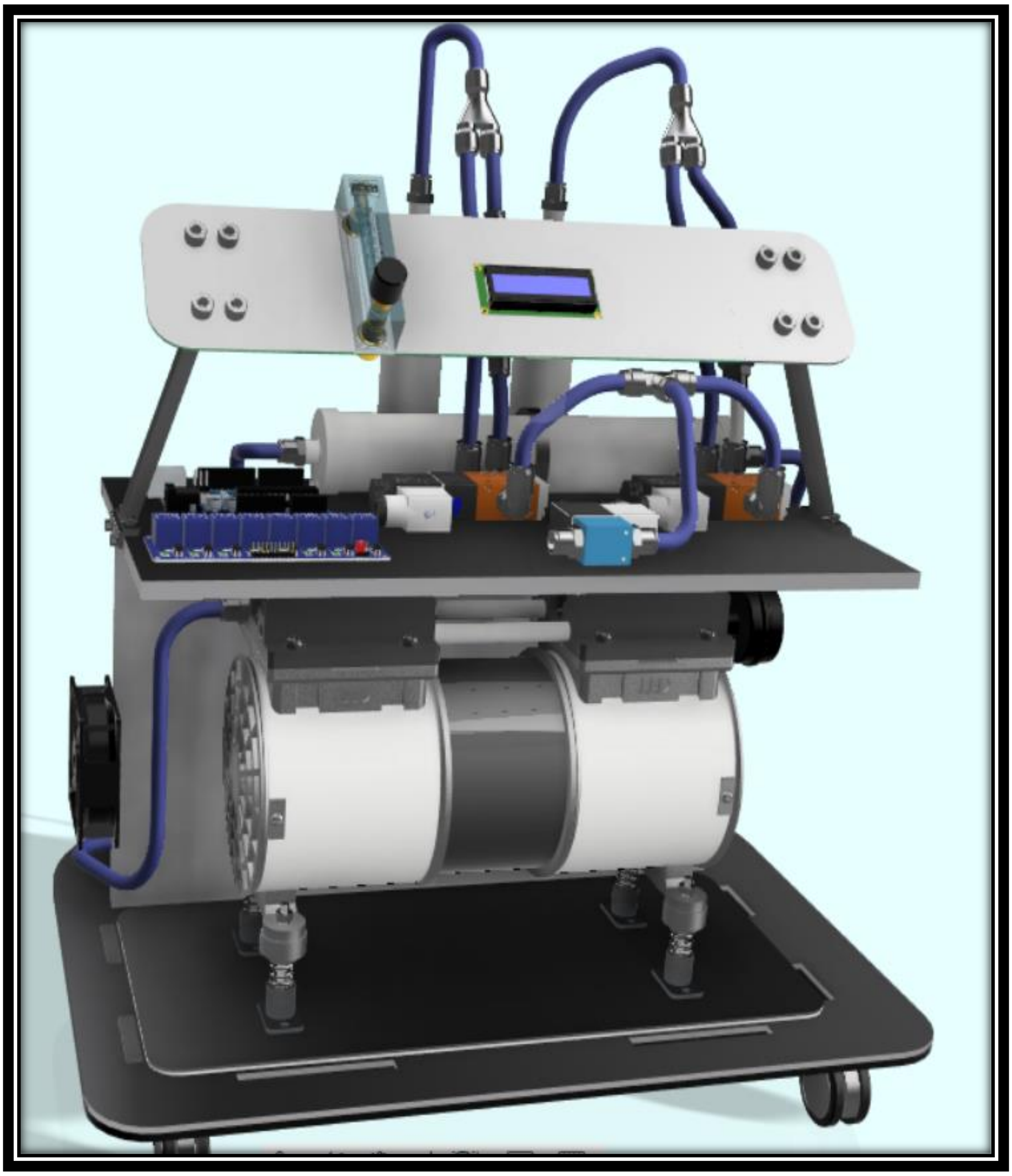


Figure 25: Assembly 3

Figure 26: Assembly 4

5. Aesthetics

Figure 27: Aesthetics A1

Figure 28: Aesthetics A2

Figure 29: Aesthetics A3

Figure 30: Aesthetics A4

6. Final Product

Figure 31: Product Image 1

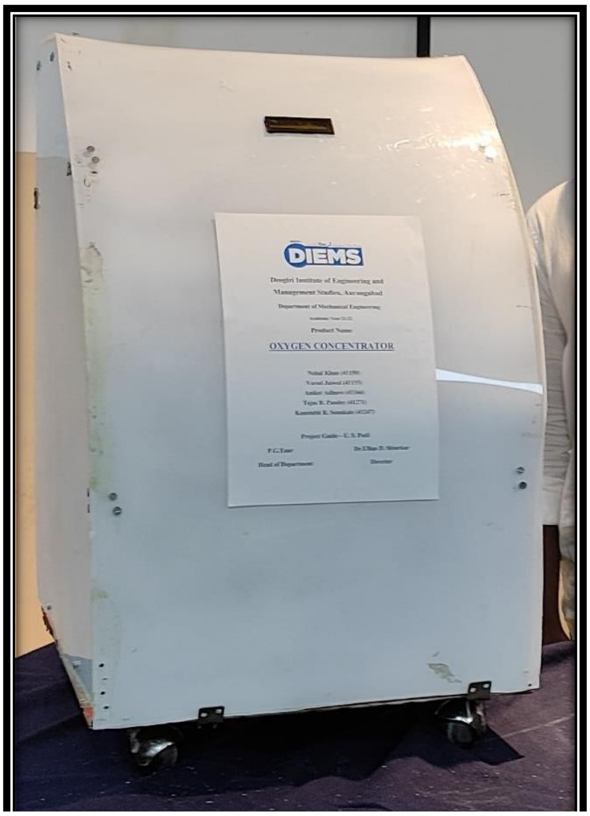


Figure 32: Product Image 2

7. BILL OF MATERIALS

Component	Total Nos	Price	Units	Single Price	Expense
Compressor	1	5750	1	5750	5750
AFR	1	800	1	800	800
Heat Exchanger	1	210	1	210	210
Solenoid Valve 3/2	4	550	4	2200	2200
Solenoid Valve 2/2	1	450	1	450	450
PVC Pipe	6	70	6	420	420
Non-Return Valve	2	100	2	200	200
Adaptor	1	120	1	120	120
Arduino Uno R3	1	550	1	550	550
Fan	1	150	1	150	150
Zeolite	1	2900	0.2	580	2900
Air Flow Meter	1	1500	1	1500	1500
Humidifier	1	260	1	260	260
Relay Module	2	180	2	360	360
Nuts/Bolts	1	130	1	130	130
Bush	2	50	2	100	100
Araldite	1	64	1	64	64
Wood	1	500	1	500	500
Metallic Fitting	6	100	6	600	600
Pressure Gauge	1	200	1	200	200
Metallic Fit Sm	2	40	2	80	80
Pipe Fittings	27	30	27	810	810
Angle Plate	2	25	2	50	50
Electrical Wires	15	10	15	150	150
Pin/Socket	2	30	2	60	60
Foam Sheet	1	200	1	200	200
End Caps	4	60	4	240	240
Cotton	1	60	1	60	60
Silica Gel	1	250	0.4	100	250
Metallic Sieve	1	80	0.05	4	80
Silencer	2	40	2	80	80
Connecting Pipes Blue	5	30	4	120	150
Fevi Quick	4	10	4	40	40
Wire Connector	1	60	1	60	60
Pipe Cover	1	40	0.25	10	40
Double Tape	4	20	4	80	80
Stickers	1	260	1	260	260
Pipe Connector	2	50	2	100	100
Cover	1	2500	1	2500	2500
Structure	1	2000	1	2000	2000
Total Manufacturing Cost				**22148**	24754

8. CONCLUSION

As we had already made an Oxygen Concentrator with 80% purification efficiency, in this semester our target was to enhance the same to over 90%. For we started by increasing the inlet pressure of the zeolite canisters, this proves very effective as the adsorption capacity of the zeolite increases with increasing pressure and decreasing temperature. We then cooled the outlet air from compressor via the heat exchanger even more using fans to direct air to HE, we also directed the cool N2 purge towards HE coils to enhance the cooling effect. This also proved effective. Initially we were working with spherical zeolite balls, to improve N2 blocking ability of zeolite we used crushed zeolite. All the above ways complemented each other and ultimately enhanced the purification efficiency of the oxygen concentration to over 90%.

In this semester (8^{th}) we had also taken the task of improving the overall cooling of the Oxygen Concentrator. For we performed CFD flow simulation and provided multiple vents and cooling fans for better circulation of air. Multiple slots were made on the compressor compartment to facilitate better circulation of air. HE was given separate fans and N2 purge.

We have studied and designed the Aesthetics and Ergonomics of the oxygen concentrator. We have selected material for aesthetics by considering different types of loads acting on it and different types of failure modes. We have chosen aesthetics material with less cost and low weight without compromising on safety and functionality. We have learned lots of new things with this project which will be very useful for us to build this project.

Figure 33:Display Reading

9. FUTURE SCOPE

1. Create a pulsating and continuously supply provision.
2. Temperature regulation as per requirement.
3. Include battery in case of power outage.
4. Reduce the overall cost.
5. Higher grade Zeolite.
6. Improve heat transfer efficiency.
7. Dynamic system.
8. Less power consumption.

ACHIEVEMENTS

1. Improved overall arrangement and use of components to consume less space thus reducing the size and weight of product.
2. Optimize the placement of components.
3. Reduce the cost of components.
4. Provision for variable oxygen flow.
5. Create a portable device.
6. Reduce size of Product.
7. Reduce weight of product.

10. REFERENCES

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