Oxygen Concentrator with Zeolites-Na: An Economic Design

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Abstract-

India is facing a serious oxygen crisis. During medical treatment, the patients are unable to receive oxygen at sufficient purity levels during the scheduled period. This work presents a detailed study of portable and hospital air separation process/device with Na- Zeolites to produce a continuous flow of oxygen to the patients who are suffering from a lack of oxygen. It recommends the implementation of an Oxygen concentrator in different markets, at homes. Developed concentrator is designed to make it easily available to the patient. The design is based on PSA (Pressure Swing Adsorption) technology.Developed prototype of oxygen concentrator is capable of supplying oxygen in variable flow rates continuously with satisfactory purity percentage.

Keywords–*Na-Zeolites- Sodium Zeolites, SDGs, Oxygen Concentrator, Oxygen therapy, United Nations, WHO, Corona virus, pandemic, molecular sieve, SpO2, Sustainable development, LPM, LRS*

I. INTRODUCTION

The shortage of Oxygen Cylinders, the practical problem of carrying along bulky cylinders manually and over vehicles, standing in long queues, in-exorbitant black marketing of oxygen cylinders, very few manufacturers of Oxygen concentrators [1] in India are few reasons making the oxygen shortage acute.

Ambulances in India especially in rural belts are not equipped with oxygen cylinders and suffering patients requiring transit to hospitals are exposed to risk.

This is the current scenario of India one of the developing country with close to 1.39 billion population .The oxygen infrastructure needs major improvement.

Motivation Examples:1. Our Senior colleague Seema Awasthi at IIT Kanpur called me up on May on April 26, over the phone one fine day desperately asking for the Concentrator availability from some store in our city to keep as a back-up for her ailing mother.I tried to help her for the next 2 days over offline and online modes in and out of Kanpur in India and to my surprise, I found very few vendors who manufactured this device here in India and due to supply chain in disruption due to lockdowns, the delivery period was also quiet long.(2).On April 9, VinodVernwal's phone call at 3 am in the morning woke me up to a horrific scenario upcoming before all of us .It unfolded that Mr.Vinod's daughter (a banker, aged 32 years of age and a mother of 2 years daughter) complained of breathlessness in the middle of night. MrVinod asked for my support at the same time. In haste, I summoned all my contacts for some oxygen aiding device/euipment but all in vain. She was admitted; however, to a hospital nearby, fortunately she got a bed as all the city hospitals were overloaded with patient's traffic. She remained on ICU support but succumbed to death 5 days later.

II. PAPER OBJECTIVES

To highlight the Why?Elaboration of the challenges of making a Minimum Viable Product (MVP)amidst lockdown in the ongoing pandemic in Uttar Pradesh, India.This paper envisages the importance of Oxygen therapy to moderate patients. This short paper highlights the methodology taken up for making the Oxygen Concentrator with minimum available resources with respect to components.

III. BACKGROUND

Help has been taken from WHO and UNICEF's technical specifications [2] and guidance for oxygen aid equipment's/devices, which is part of the WHO *medical device technical series*,1 and relies on inputs taken from experiences of citizens of China and other countries including officials and common man. Oxygen therapy [3] has been advisedall severe and critic patients infected with corona virus , with low doses ranging from 1-2 L/min in children and 5 L/min in adults with nasal cannula, moderate flow rates for use with venturi mask (6-10 L/min); or higher flow rates (10-15 L/min) using a mask with reservoir bag. The main focus segment is Low and middle-income groups of the third world countries.

Need of the hour – target device – Oxygen Concentrator

Upon infection from corona virus, the lungs capacity to send oxygen to body cellsdeclines [5] and upon reaching a minimal threshold level, the person feels breathlessness and oxygen level of supply to cells reaches reduced alarming levels .This is called hypoxemia. Oxygen input is given to such patients via devices like Oxygen concentrators to help the patient to sustain his breath at the optimum levels. The role of concentrator becomes all more important here as this serves the very purpose of relieving a patient from breathlessness [6]. SpO2 is the oxygen saturation levels in the human blood cells. This indicates the measurement of Red Blood Corpuscle (RBC) Oxygen carrying capacity to various body organs from the patient's lungs. SpO2 [7] – thearterial oxygen saturationlevels of normal lungs in a healthy person is - 95% – 100%.

IV. ZEOLITE DISCUSSION

Nowadays, Li-X zeolite and Na- Zeolites are the best sorbents for use in the separation of air by adsorption process. Pressure Swing Adsorption PSA technique has been more and more widely been used by researchers and device makers. In this work, we have used type X zeolites containing Na and also varying mixtures of sodium with 4mm to 8mm granules.

V . RELEVANCE OF OXYGEN CONCENTRATORS IN UP

The UP Government has now launched the campaign of – "**My village – Corona free village**" With focus on increased vaccination and medical aid at the Health centres. Oxygen aiding devices also need to be put up there. We are also feeling the dire need of such concentrators in at least 58,000 Village communities called Gram-sabhas here in India,2000 Health Centres and 600 Community Health centres[14] and 75 district hospitals in the state of Uttar Pradesh. We needto manufacture and supply these devices via government departments like the MSME/Medical Universities, Self-Health Groups ,Village-vigilance committees called Nigranisamitis here in the state of Uttar Pradesh UP, India and Village heads .Meticulous resource plan needs to be in place.

VI . RESEARCH TECHNOLOGY

A. *Oxygen Concentrator*

Elaboration- Medical Usage for oxygen therapy - Used to deliver oxygen at the bedside or within close proximity to patient areas. A single concentrator can service several beds with the use of a flowmeter stand to split output flow.

Neo natal babies often suffer from pneumonia disease in low and middle income group countries and Low Resource Settings [LSR] and they normally require 4-5 days of dedicated oxygen therapy. Oxygen Concentrator (OC) can be a suitable solution to this.A self-contained, electrically powered medical device designed to concentrate oxygen from ambient air, using Pressure Swing Adsorption (PSA) technology. The oxygen so produced can be stored in surge tanks for usage later, if required.Also, many rural ambulances are ill-equipped with oxygen cylinders.Likewise, we have 75 districts in the state of UP with a District Hospital with an average of 5 ambulances. These hospital ambulances can be allotted 2 concentrators each as a backup to fight the situation while being at the patient's residence and while being in transit to the hospital.

B. *Construction & Working Methodology*

A concentrator consists of a compressor and sieve bed filter [8]. The air is pushed into the zeolite columns and pressure maintained too with the help of this compressor. Zeolite plays an important role in separating Nitrogen from the pushed air. The two columns of Zeolite sieve beds perform functions of separate Oxygen and Nitrogen from the air and simultaneously removes the Nitrogen out of the columns. This cycle creates a continuous loop of fresh oxygen to the patient and release of Nitrogen to the atmosphere.Briefly, an oxygen concentrator uses PSA [9] technology (fig.3) to take in air from the surroundings, the nitrogen is separated to generate oxygen for more than 90% concentrated oxygen [10], [11].

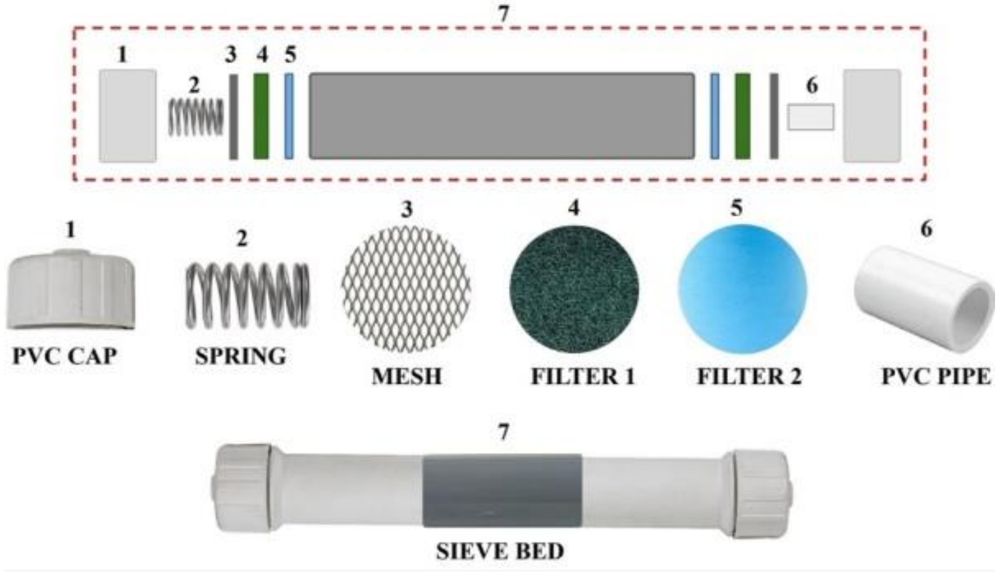

Fig. 1. Zeolite Column Assembly[Source – self created]

It should not be used if the oxygen concentration falls below safe limits. Oxygen concentrators can be carried along and being less in weight are manageable to be carried in vehicles like ambulances and can be kept by the bedside of a patient with a variable flow rate of between 0-10 L/min.Compressor provides the ambient air to the sieve bed via the heat exchanger. Heat Exchanger transfers the heat from one place to another, Sieve bed performs the PSA cycles.

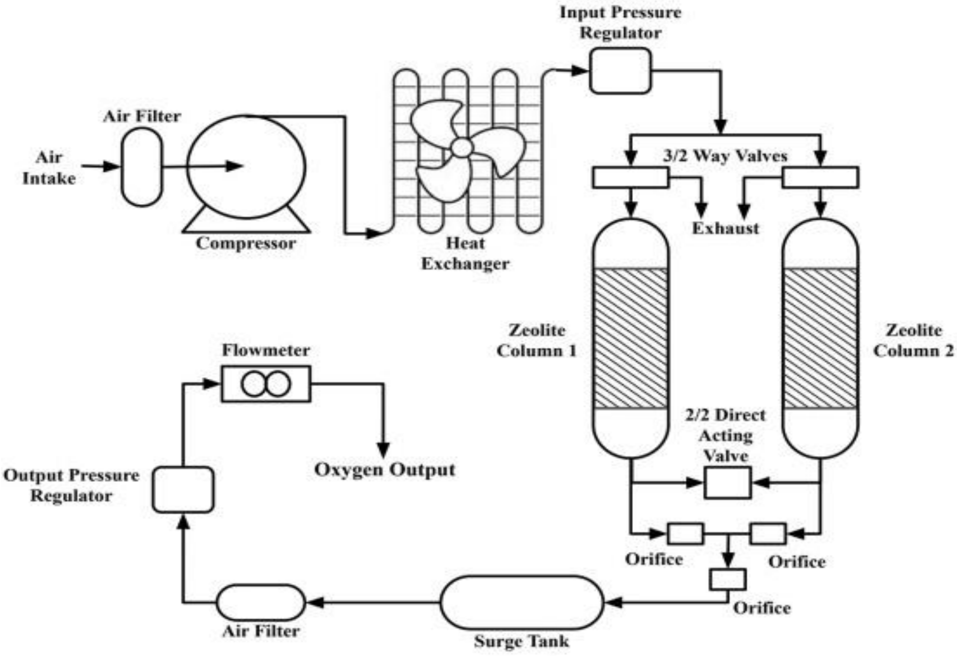

Fig. 2. Flow diagram of Oxygen Concentrator[Source-self created]

Intermittent stable electric supply is imminent for an Oxygen Concentrator. 0-10 LPM Litres per minute flow requires between 220-240 V AC (fig. 4),a quality, and non-stabilized power flow. 220V AC is converted to 12V DC through a Convertor making seamless flow. A voltage stabilizer is an important device here to maintain incessant power supply to the device.

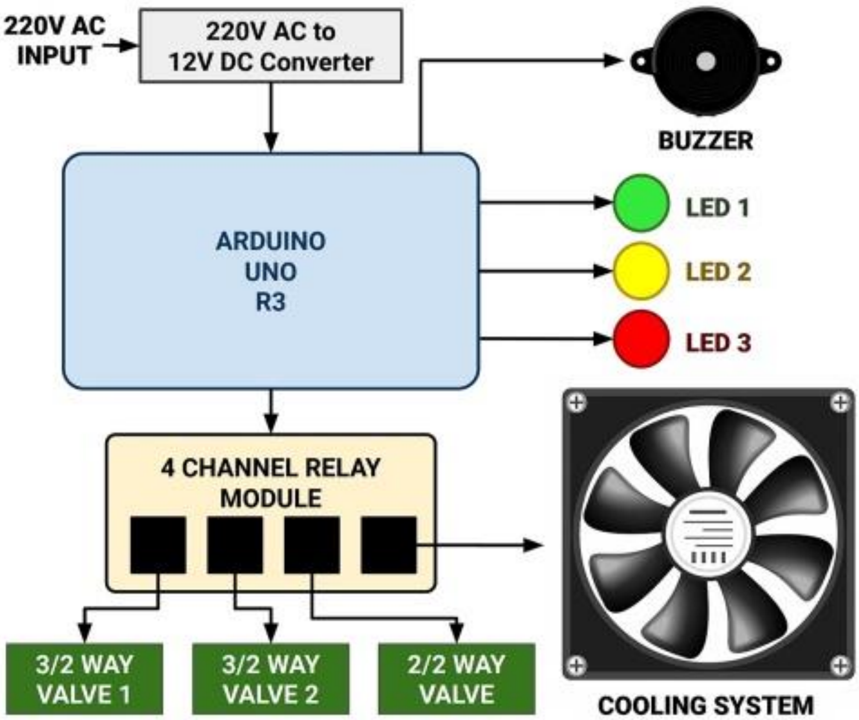

Fig. 3. Circuit block diagram of Oxygen Concentrator

The Bill to Material (BTM) is INR 35,000/- and after testing cost and certification cost, it shall cost around INR 47,000/-. The prototype device matches with the schematic in fig.3 with 3 relays and 12V DC adaptor, 3 LEDs, 4 blowers plus 2 blowers in radiators, buzzer, MCB, Connector ardino Uno R3.

Novel and original ideas been used:1. Oxygen Concentrators (OC) are usually meant for long continuous running which heats up compressor resulting in quick wear of the compressor. We experienced problem of overheating of compressor. To facilitate cooling of the compressor fins, we have customised computer CPU cooling radiator to be used in place of heat exhanger and it is serving well, its objective. This radiator has an inlet from the compressor and an outlet going to the water separator.

2. On the practical front, we experienced problem of oxygen purity. We have worked on 4 different combinations of zeolite with activated alumina to extract oxygen purity with the help of indigenous available zeolite Sodium zeolite in place of Lithium zeolite which we import from China. Majority PSA based models use Lithium zeolite as adsorbents.

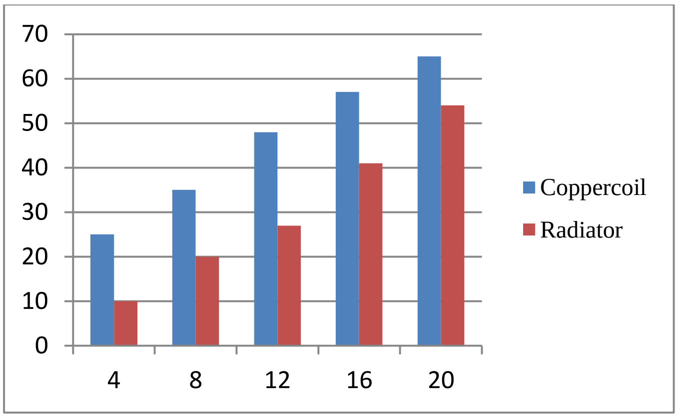

Figure 1: Bar Graph

Table 1: Comparative Analysis

Hours	Compressor	Compressor
Duration	Copper-coil	Radiator
4 hours	25	10
8 hours	35	20
12 hours	48	27
16 hours	57	41
20 hours	65	54

VII. Development Of Oxygen Concentrator

A low cost Oxygen Concentrator is developed in workshop, which is capable to deliver oxygen with variable flow rate (0-10 LPM).

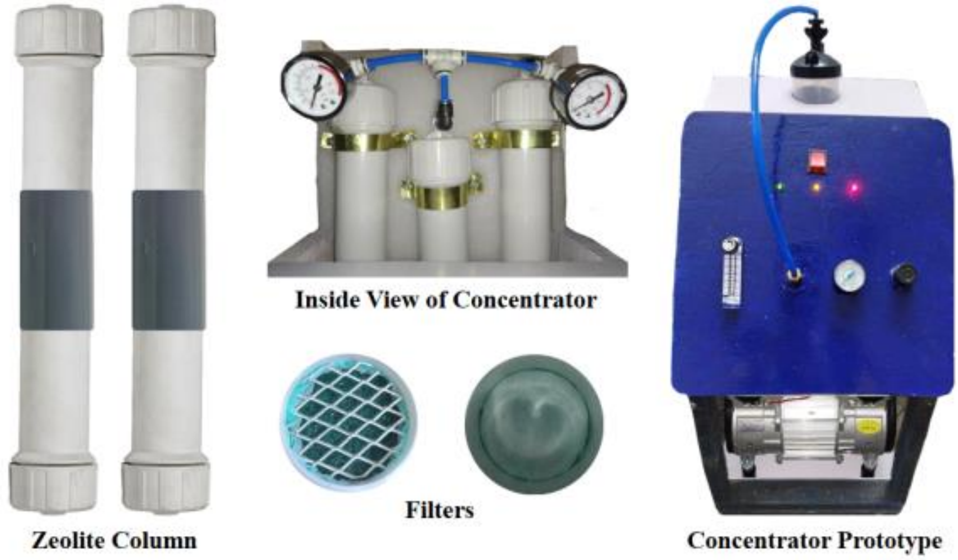

Fig. 4. Developed prototype of Oxygen Concentrator

Certification of medical equipment – We have tied up with three hospitals to get these devices tested for efficacy and continuous usage. We have not got it tested till now. If the device is tested successfully on the hospitals parameters then we shall send it for certification by the India's Health apex body ICMR(Indian Council for Medical Research)

Public safety – Our team has decided to appoint training personnels to educate the attendants on the device's upkeep like filter change and cleaning. Also various Do's and Dont's for the device need to be told like 1. No inflammable material(petroleum, oils, paints, grease etc.) in the patients room. 2.No smoke zone 3. Device to be kept 2 feet distance from the walls for ambient-air availability. 4. Weekly check of filters and daily external cleaning with dry cloth
Ethical issues – During the development of this prototype, we have taken care not to breach upon other companies devices modelling and remain original in our approach for zeolite combinations, compressor cooling system, compactness of the device and fabrication.

VIII. CONTINGENCY PLAN

B. Development process of current MVP at our lab cum workshop

The development process started with a virtual meet review of coming up with an innovation of oxygen therapy product like oxygen concentrator. A consultative process with project stakeholders and experts was used to identify components, technology and timelines in the challenging environment of raging corona virus spread, resulting deaths and lockdown across the cities.

C. Stage of development of the device at our lab cum workshop

Due to lockdown of establishments dealing in component trading/manufacturing could not be accessed by our procurement team and disruption in supply chain and disturbed logistics.Tasks performed during MVP development(usage of team-member name has been spsecifically taken)
Procurement –For zeolite availability, Exploring online vendor details by Ms.AvikaPal and Mr.ShivamShukla helped us procure essential commodities such as zeolite and compressor on Indiamart and Amazon.

Researc**h –** The PSA science and roles of zeolite, water separator, valves, heat exchanger and compressor was meticulously handled by Dr. AparnaDixit with initial options to use scrap material.
(football bladder as cannula, scooter compressors for taking in ambient air),timelines to complete MVP(May-end)and budget to make (INR 25-30,000/-).

Development – The coding part for the relay cycles to occur between adsorption and deadsorption cycles in the sieve bed was done by the development team of Mohd. Uvais and RaghavDwivedi. The programming work done for the Printed Circuit Board (PCB), creating sieve bed out of zeolite and pre-carbon cylinders was also done by this team.

Marketing – The liasioning work with various vendors for procurement of zeolite and components were done with the help of Founder of one start up – Sangrah Innovations.

Sangrah Innovations did not had any role in this product development and our oxygen concentrator is in no way related to their products.

IX.CHALLENGES DURING CREATION OF OUR MVP (PERMISSION TO USE NAMES OF TEAM MEMBERS HAS BEEN SPECIFICALLY TAKEN)

1. Before getting down to making this medical device, none of us had any idea of making this device. This work was carried forward by Dr. Aparna Dixit, Mohd. Uvais, Raghav Dwivedi under the mentorship of Dr. Sreeram Dhurjaty Sir. Various flow charts depicting the flow of air along with relay cycle were studied with discussions about the model alternatives, we could use in place of ‘off the shelf’ components in the marketplace.
2. Shutdown made things inaccessible for building up this model.
3. Our team used wood and scrap material from packing boxes.

X.ANALYSIS ON WEAKNESSES AND STRENGTHS AND ACTIONABLES TO OVERCOME THOSE:

1. Our knowledge on the subject in context was very little at the beginning. Due to diligent efforts from the research team, we got through different milestones of creating and building up the model
2. Shutdown during the pandemic surge was the biggest hurdle
3. Vital instruments to measure the results were not available to us for a long time like oxygen flow meter and oxygen analyser .We got through this via online mode Amazon and Indiamart.
4. With people from the technical background with vintage and diverse mix of people from research, software development gave us the required confidence to move ahead.

Justification in terms of Relevance, Validity, Contribution, Rigor, and Clarity:
Times of distress compelled to innovate the MVP based on indigenously available Sodium zeolite. This unit is a relevant and valid work for people in quarantine and in transit to hospitals Team’s contribution in terms of study, research, procurement and development gives a clarity to our objective of making Minimum Viable prototype (MVP) with rigor in timelines and budget.

Actionable recommendations and way forward:

1. Testing, re-prototyping, certification and replication
2. Deployment of OCs in due consultation with local government agencies at PHCs/CHCs in the rural belt with little health infrastructure on oxygen therapy
3. Building up repair and service providers’ team to give assistance to staff at the health centers post deployment of the devices.

We have a clear vision to strengthen the countryside health centers on oxygen therapy infrastructure with units of oxygen concentrators deployed with long term services in place.

Methodology – Out of two research designs studied by us for producing oxygen – Electrolysis and Pressure Swing Adsorption (PSA) , we decided to work on the PSA technology as Electrolysis method involved proper lab environment for testing else it posed risk to testers.

We created a blue print of the device with calculations using equations related to gas pressure (PV=nrt) for configuring our sieve bed and zeolite composition. We procured 4mm to 8mm Sodium zeolite granules to move ahead in place of Lithium zeolitealong with catalyst activated alumina. Testing procedure and quantitative results with data findings as follows:

SIEVE BED COMPOSITION	Oxygen purity
Only Sodium zeolite	50%
70% zeolite + 30% alumina	55.5%
100% zeolite +100% alumina	75%
Pressure @10LPM flow	82%

Pressure @10 LPM constant	Oxygen purity
20 psi	50%
22 psi	55%
25 psi	65%
30 psi	80-85%

These interventions with zeolite and pressure combinations, we are able to evaluate the consequences. The strengths of this model in terms of providing 10 LPM flow at competitive price makes this unit unique. Sodium zeolite usage with 80+% supports its replication and external validation.

XI.CONCLUSION

.Rural areas with even lesser infrastructure at disposal for the population are more prone to such pandemic contingencies and we wish to support this fragile framework of rural/countryside health services with regard especially to concentrators.

XII. ACKNOWLEDGEMENT

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