Project Apollo v4 – auto-tuning

# Problem statement

COVID-19 patients with severe and critical conditions need respiratory support including bag-valve-mask ventilation, noninvasive mechanical ventilation (NIMV), high-flow nasal cannula oxygen (NFNO), mechanical ventilation and other protocols [[1]](#footnote-1) [[2]](#footnote-2) [[3]](#footnote-3) [[4]](#footnote-4). In some cases, medical protocols also apply to COVID-19 patients in home care [[5]](#footnote-5).

Medical equipment used in such scenarios needs a source of oxygen. Normally, medical-grade oxygen is available from distribution networks who provide it bottled form shipped to hospitals or care centers.

However, in developed countries, an oxygen distribution infrastructure is missing. In those cases, hospitals need to improvise make-shift medical oxygen generation sources.

This document details an oxygen generation design that addresses that gap. Apollo is an oxygen concentrator design that relies on the classical PSA (Pressure Swing adsorption) process, commonly used in commercial-grade oxygen concentrators.

A key goal of Apollo is reliance on low-cost materials and inexpensive tools. The device be built in large quantities using inexpensive materials and low skills in developed countries. The oxygen generator can be easily maintainable by local crews. It can be adapted to the particular needs (oxygen concentrator and flow) that the local medical care centers require.

# Goal

This document details the procedure for optimizing/fine-tuning parameters for optimal generation.

Out of the box, Apollo can provide 5 liters/minute oxygen-rich air with about 45% oxygen concentration. This is already good enough for the majority of COVID-19 patients.

However, critically-ill patients need higher concentrations of oxygen, as high as 90-93%.

**The goal of this document is to produce a generic optimization technique that can result in 5 liters/min @ 93% O2 concentration using the Prototype v4 Apollo setup (two 2L zeolite tanks with 13x zeolite).**

# Theory of operation

The design relies on a traditional PSA (pressure swing adsorption) technique using a cyclic Skarstrom approach. More details can be found in the Wikipedia [article](https://en.wikipedia.org/wiki/Pressure_swing_adsorption) or in [several](http://kexhu.people.ust.hk/ceng521/521-7.pdf) [documents](https://www.hindawi.com/journals/isrn/2012/982934/).

A [document](https://docs.google.com/document/d/1H08QvAtLe1W1NSTmdu_J57IfZpbp_WVVHQljT--lUuo/edit#heading=h.993onhfvf5) titled “Theory of operation” on Google Docs describes an optimized cycle. More research articles can be also found on Google Docs in a separate [folder](https://drive.google.com/drive/u/0/folders/1Xf_g52wBhaAFwEMlXoqpiL8xS9xUwcvg)

One good reference to the industry-level designs of oxygen generation using PSA process can be found in this article[[6]](#footnote-6).

# Testing approach

We will run multiple tests sequentially on the same prototype using slightly different parameters.

A test reset procedure will be performed before starting each test

1. Dump the contents of the O2 storage tank
2. Check for water separation

# Controlled parameters

1. charge cycle timing (the half-cycle time interval)
   1. 6 seconds … 15 seconds with 0.5 second increment
2. flush time timing (the duration of the flush valve being open at the end of the cycle). This time interval is part of the charge cycle above.
   1. 0.1 to 3 seconds with 0.3 seconds increment
3. Regulated input pressure (manually adjusted)
   1. 15 to 25 psi with 2 psi increment
4. input flow rate (manually adjustable needle valve at the input of each tank).
   1. Actual measurement = psi increase per second at the end of the tank
5. Cross-tank bleeding orifice (if present in the configuration)
   1. Actual measurement = psi delta per second in the original tank after input removed
6. (when implemented in design) max zeolite tank pressure (when the max is reached, do not feed more air using a separate “stop feed” valve)

# Measured data

1. O2 concentration at output
2. Pressures at the zeolite tank input
3. Pressures at each tank output
4. Gas temperature at input (sensor needed)
5. Gas temperature at output (sensor needed)

1. Halacli, B., Kaya, A., & Topeli, A. (2020). Critically-ill COVID-19 patient. *Turkish journal of medical sciences*, *50*(SI-1), 585–591. <https://doi.org/10.3906/sag-2004-122> [↑](#footnote-ref-1)
2. Oxygenation and Ventilation, Module 4: Ventilation Management [American Heart Association] ([link](https://cpr.heart.org/-/media/cpr-files/resources/covid-19-resources-for-cpr-training/oxygenation-and-ventilation-of-covid-19-patients/ovcovid_mod4_vntmgmt_200401_ed.pdf?la=en&hash=DC07E68C015549A42991BC67BA674DB196D7EDC8)) [↑](#footnote-ref-2)
3. COVID-19: Respiratory support outside the intensive care unit ([link](https://www.thelancet.com/pdfs/journals/lanres/PIIS2213-2600(20)30176-4.pdf)) [↑](#footnote-ref-3)
4. Respiratory Support Strategies For Severe COVID-19 ([link](https://healthmanagement.org/c/icu/whitepaper/respiratory-support-strategies-for-severe-covid-19)) [↑](#footnote-ref-4)
5. Covid-19 and the role of oxygen in palliative care at home ([link](https://www.cebm.net/covid-19/covid-19-and-the-role-of-oxygen-in-palliative-care-at-home/)) [↑](#footnote-ref-5)
6. [Ackley] Medical oxygen concentrators a review of progress in air separation technology ([link](https://drive.google.com/file/d/1dPULuKNCiH3EcBG6xAv42wm_5slU8NQf/view?pli=1)) [↑](#footnote-ref-6)