DRAFT

OXYGEN CONCENTRATOR TEARDOWN AND REVERSE ENGINEERING

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Theory of oxygen concentrators

A typical home use oxygen concentrator uses the “pressure swing adsorption cycle”. This employs a “molecular sieve”, in this case a high-surface-area granular medium that selectively adsorbs nitrogen onto its surface, at high pressure. When high pressure air is flowing through such a medium, nitrogen is adsorbed onto the medium, leaving relatively high purity oxygen flowing through.

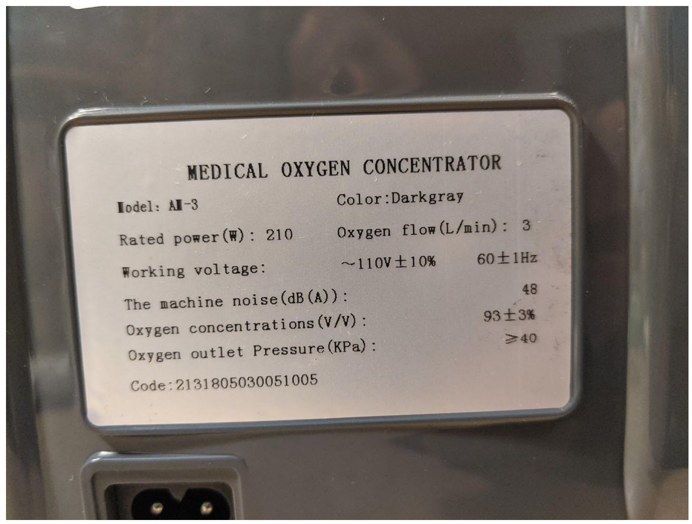
At some point the medium becomes saturated, so it is necessary to remove the nitrogen. This is done by reducing the pressure and flushing the medium with air (or, in this unit, purified oxygen).

While we are flushing the medium, it is desirable to continue the unit’s operation. So typical units use two adsorption columns, operating in an alternating pattern: When one is adsorbing, the other is flushing, and *vice versa*.

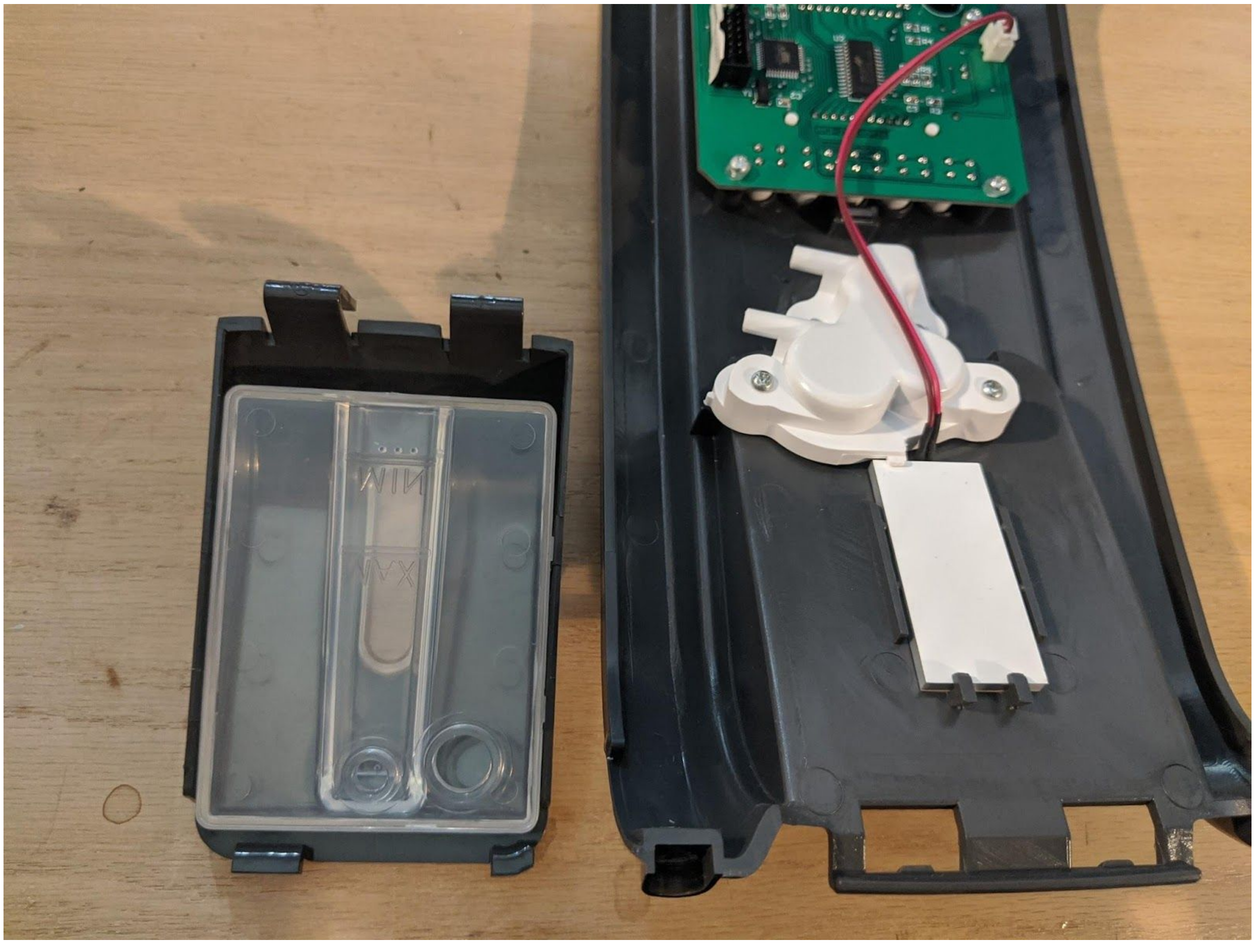
This is a very brief overview. Wikipedia provides a longer discussion. This document focuses on the actual design-build of a modern unit, and is intended to serve as a reference for emergency designs.

Overall machine teardown

I got this portable oxygen concentrator from China on Ebay. See the external appearance below.



External appearance and “specs”

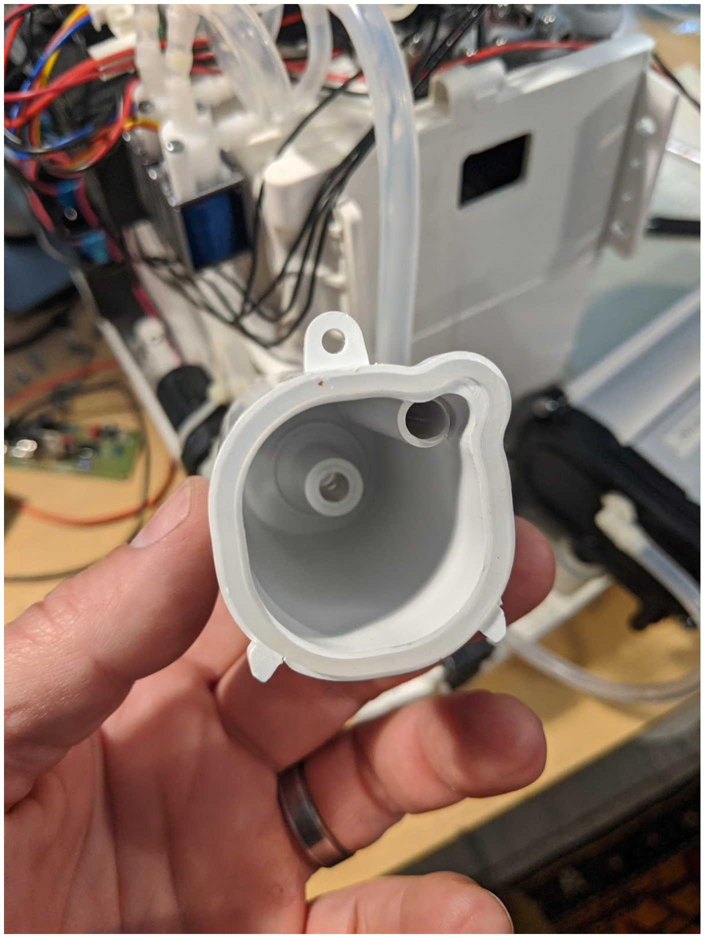


Front plate removed, to show humidifier vessel and oxygen outlet manifold

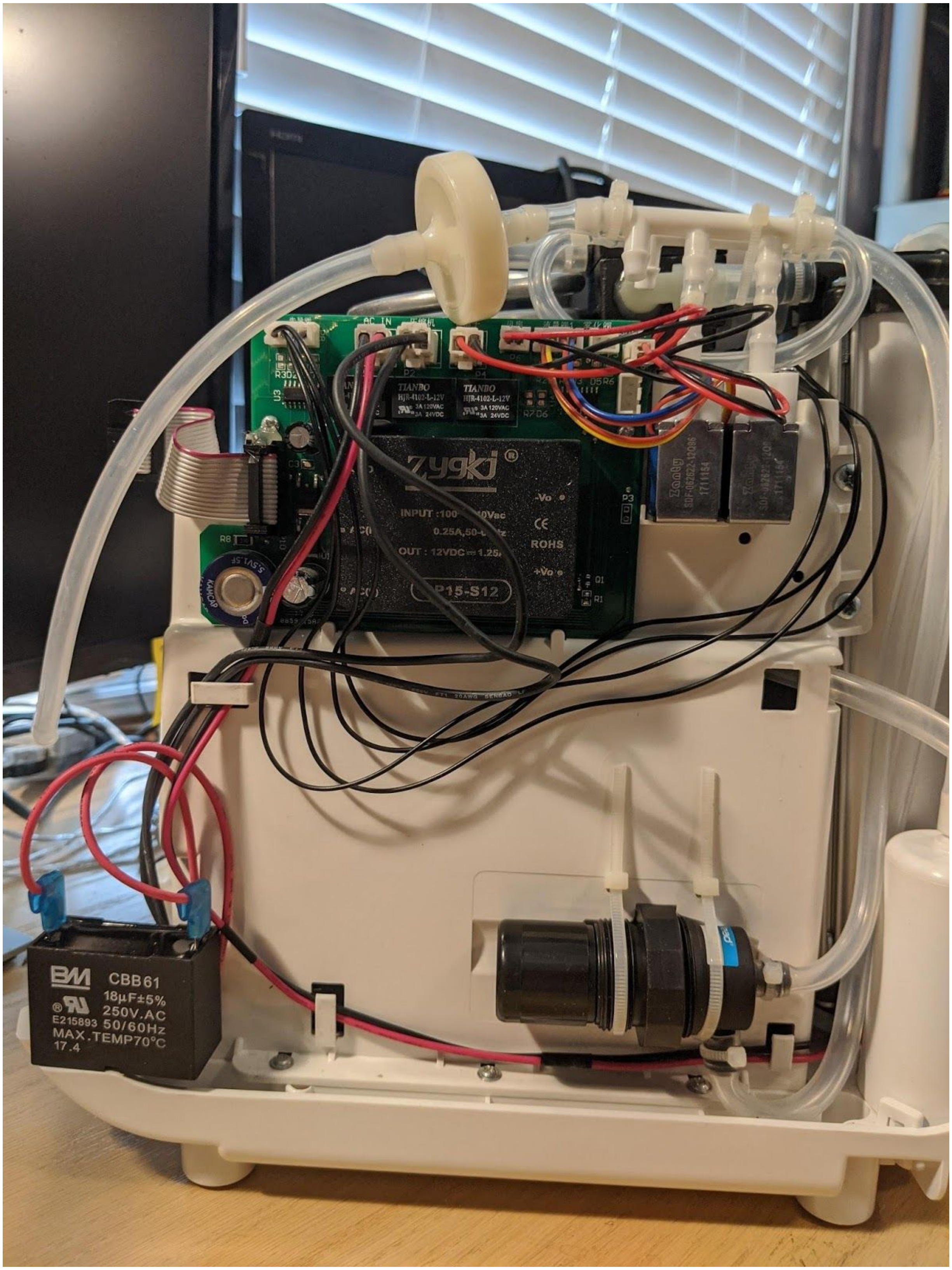
Side plate removed, to show back of the HEPA inlet filter housing

Inlet muffler / resonator chamber

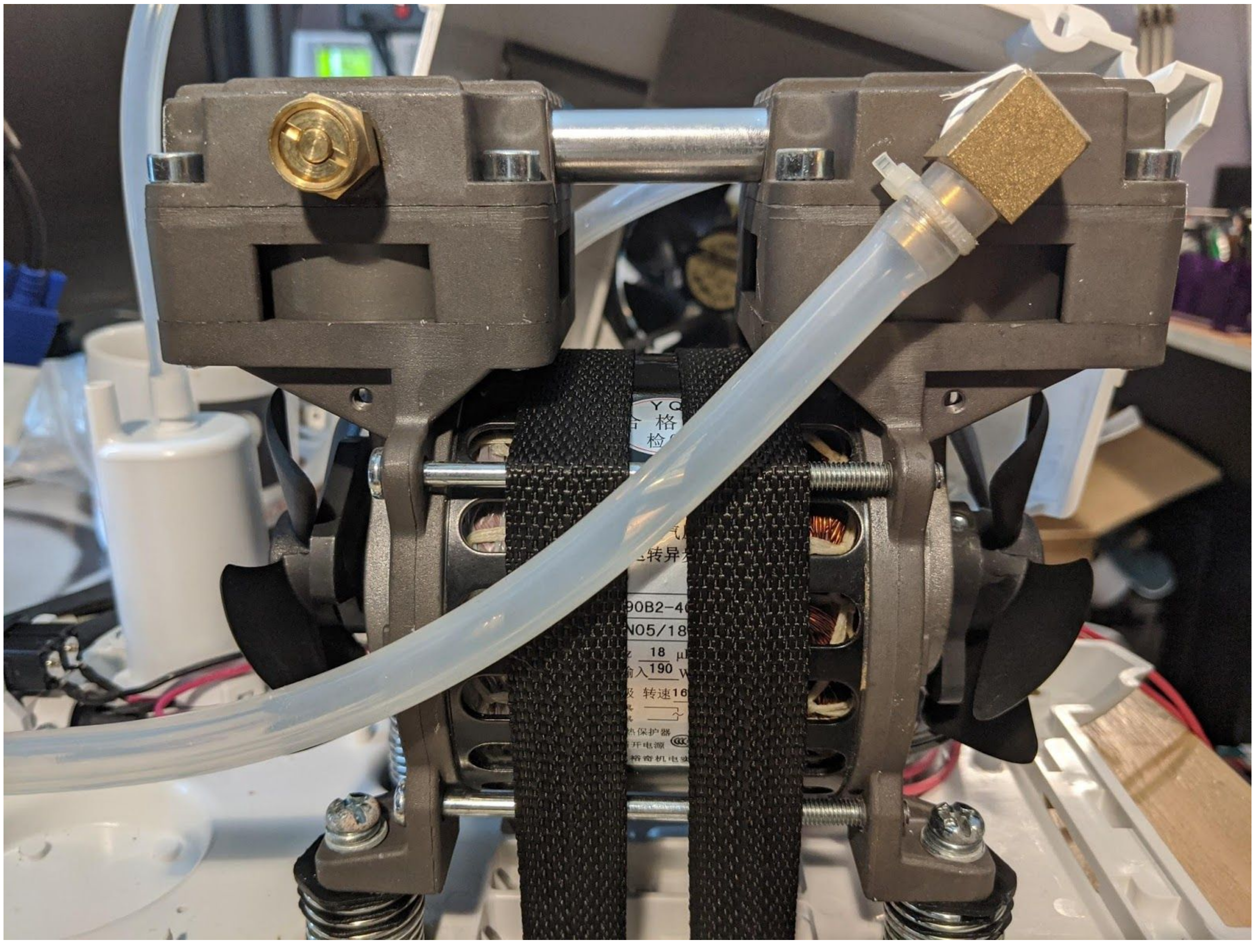
Another view of inlet muffler / resonator



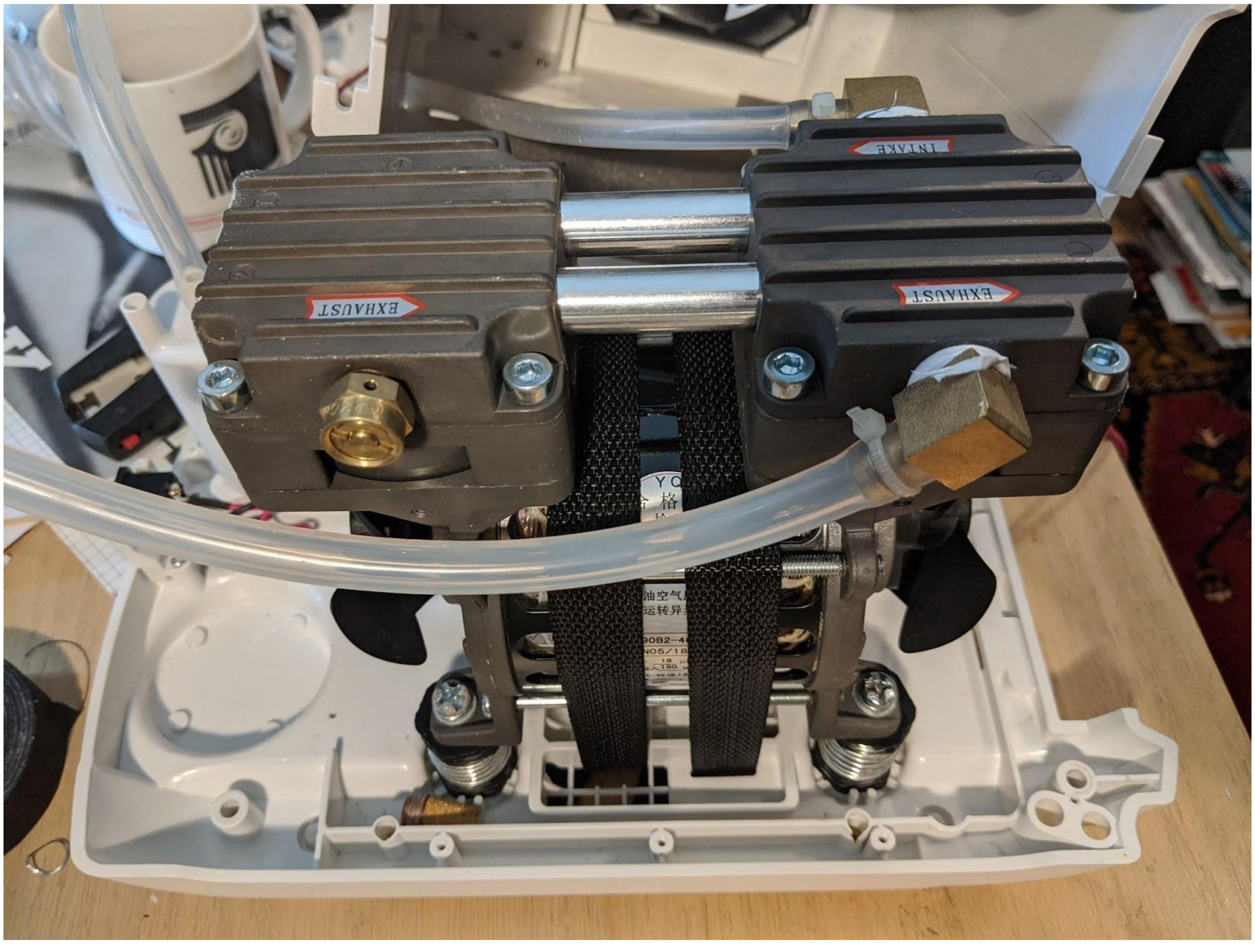
S00per s1mple. Also unnecessary in an emergency situation



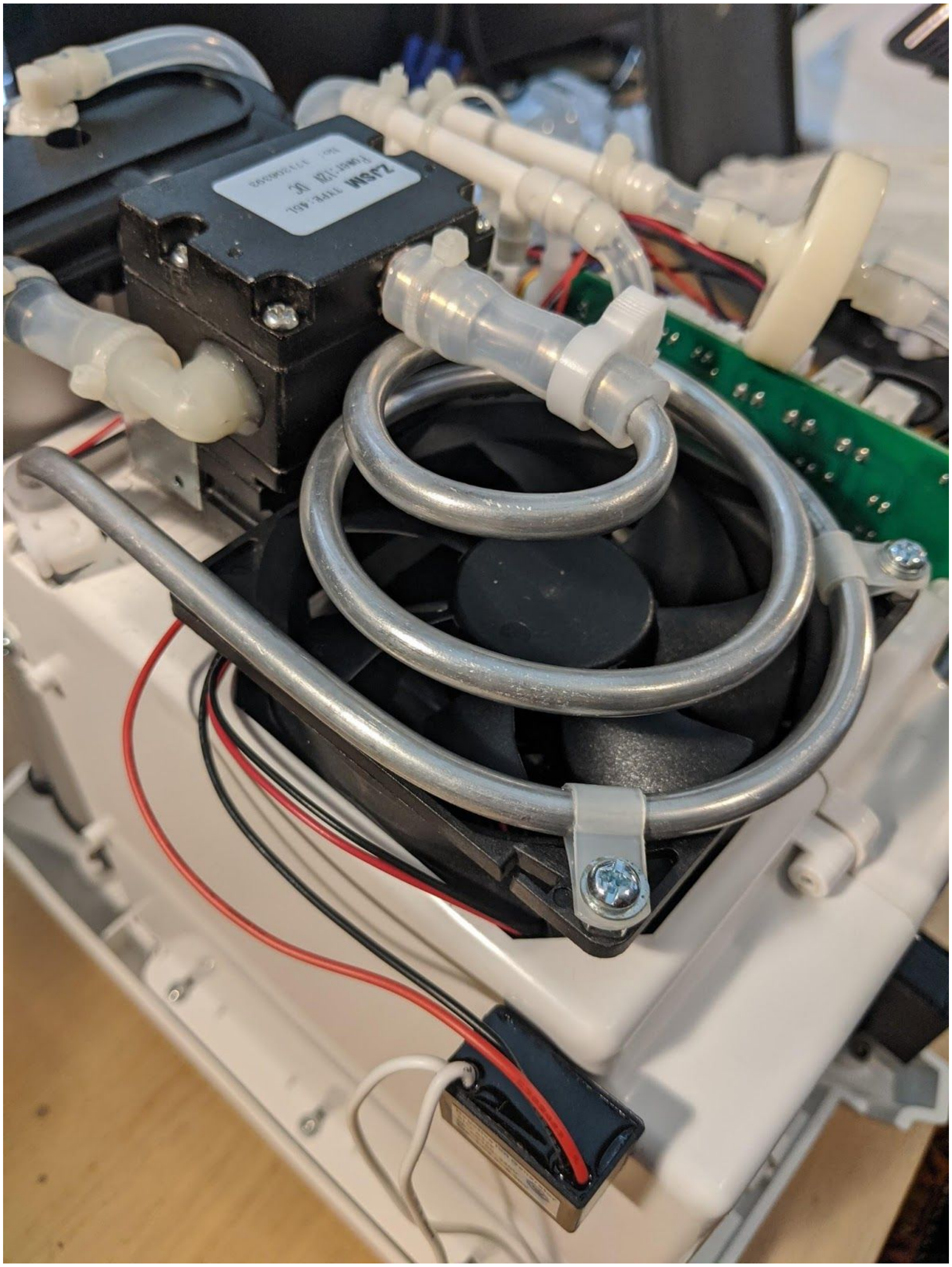
Side view of machine, showing compressor housing, inlet muffler, output filter, output flow valves, and control board



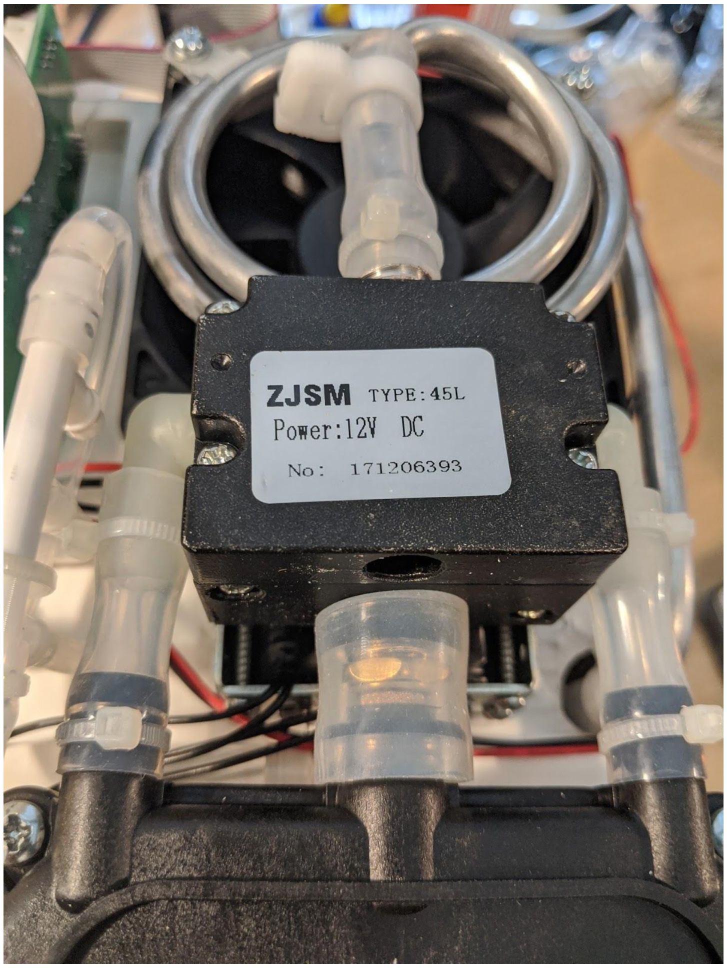
A side view of the compressor. Double-cylinder, parallel acting (alternating)



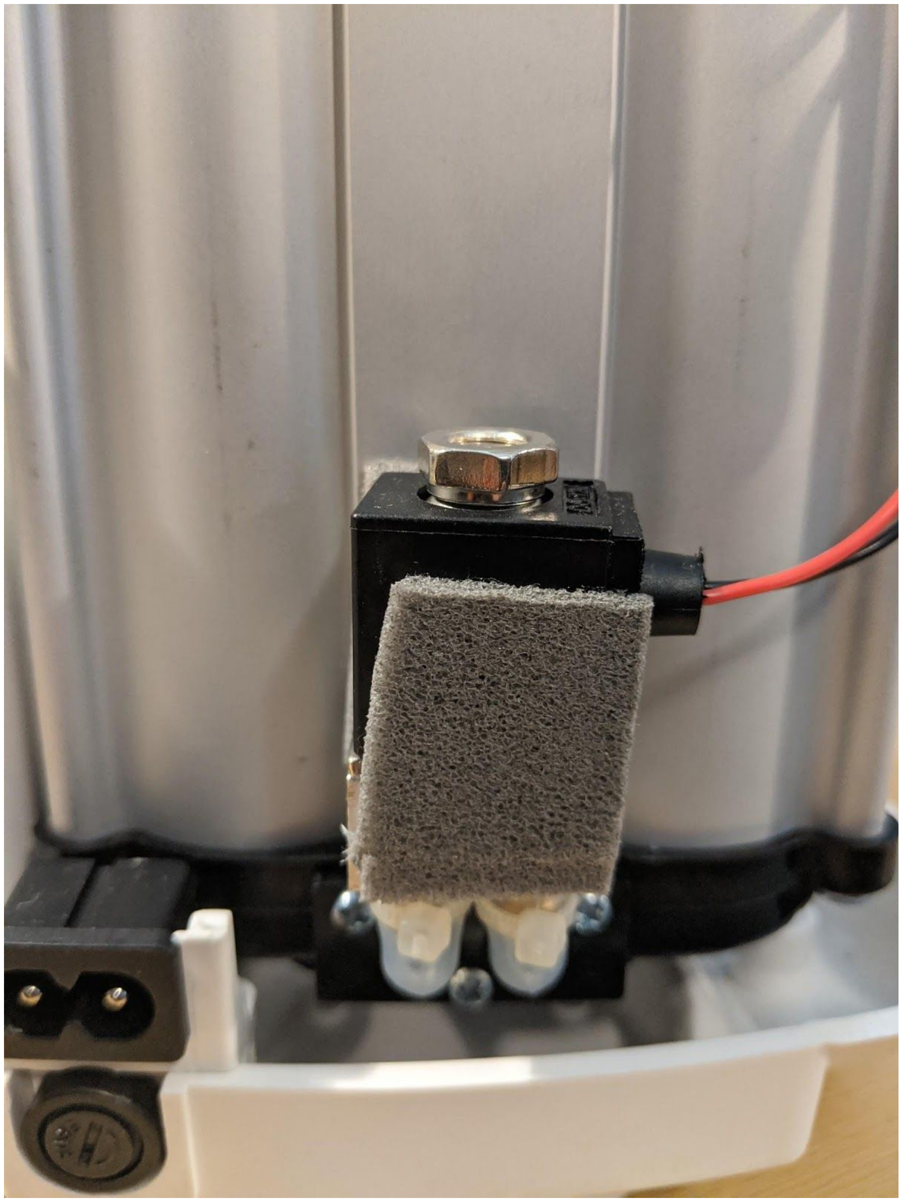
Another view of the compressor



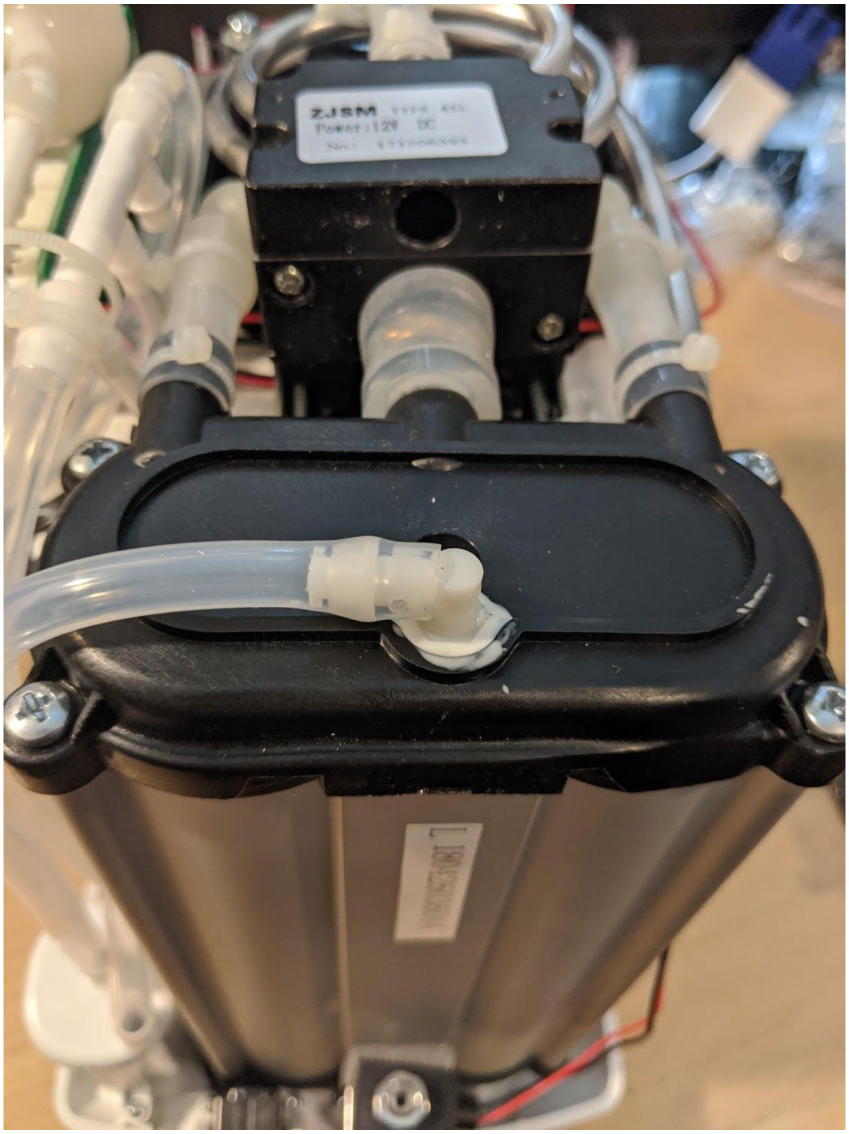
The compressor outlet is fitted with a fan-cooled condenser coil, to dry the outlet air (don’t want to poison the adsorption columns). Dry, high pressure air is routed to the “P” port of a dual solenoid valve



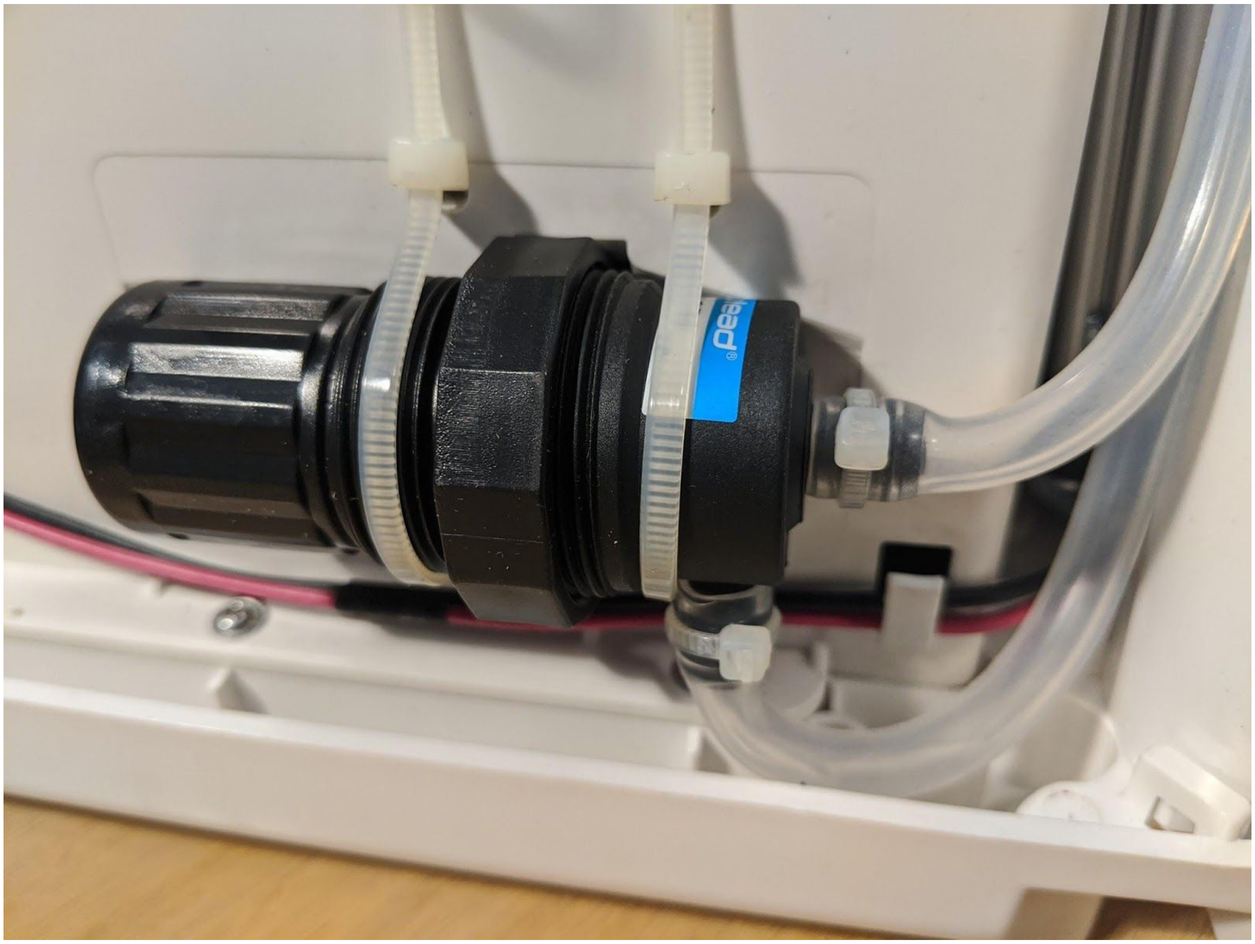
Dry, high pressure air goes to the "P" port. The "A" and "B" outlets go to columns A and B. The exhaust port goes to a little sintered bronze muffler



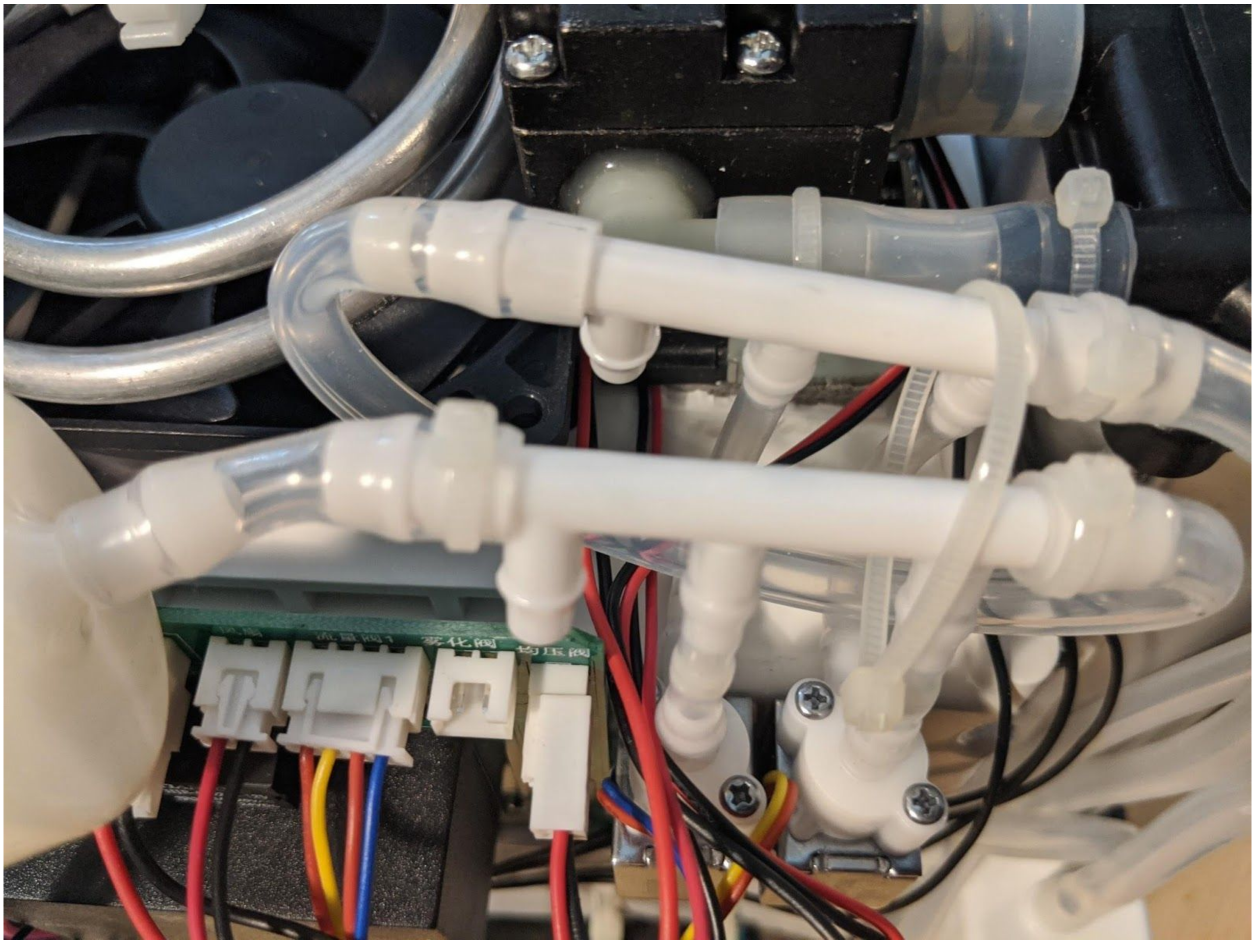
There is a bidirectional, two-port “precharge” valve between the bottoms of column A and column B



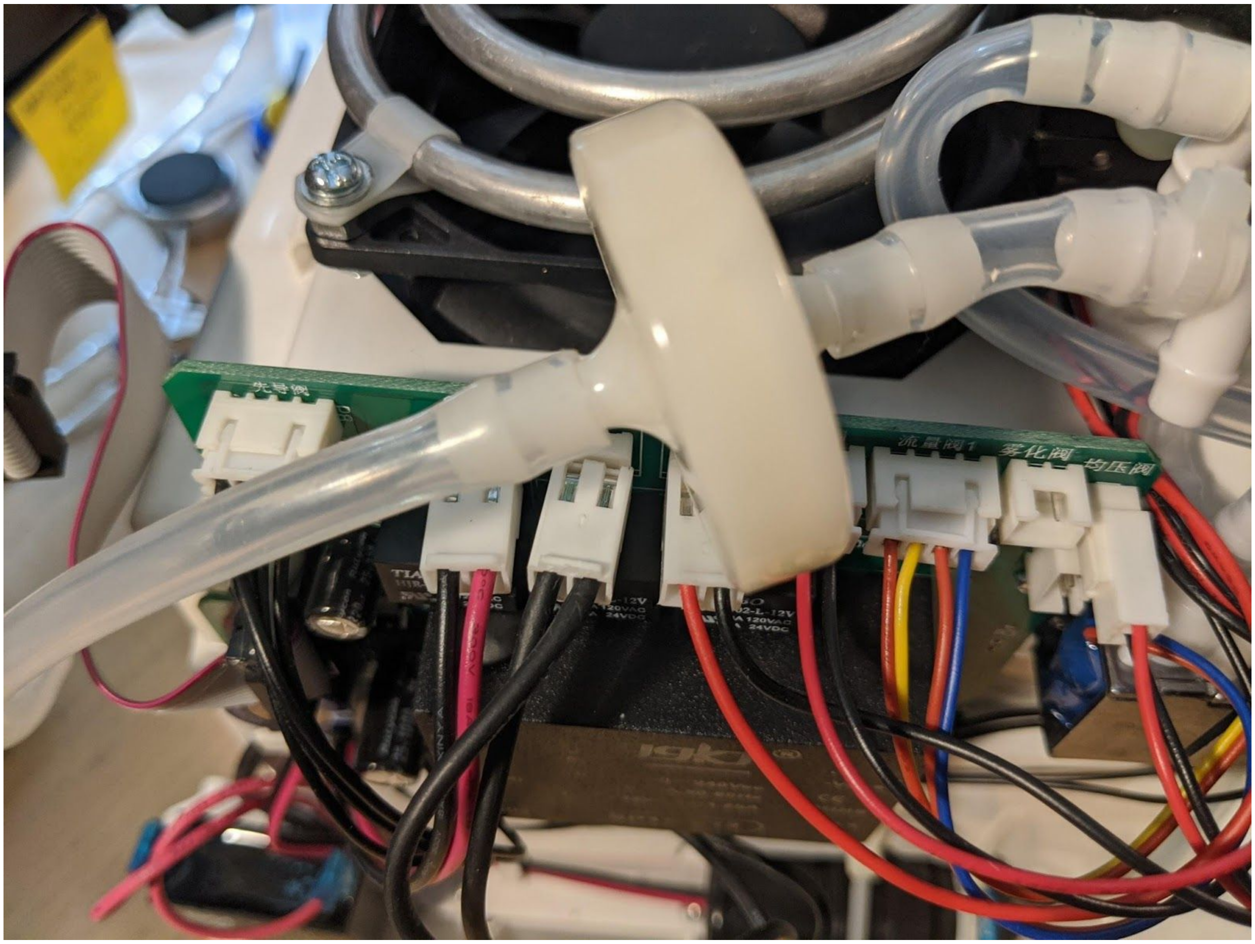
The outlet from both columns is channeled up through the aluminum extrusion, to the outlet port



High pressure outlet port goes to the pressure regulator. This smooths out the flow from column A or B or A+B, and provides uniform pressure to the outlet flow restrictors



There are three outlet flow restrictors, each passing approx. 1 liter per minute. They appear to be high-density cellulose filter plugs? They are all in parallel. One is always active. The other two are opened by one or both outlet flow valves

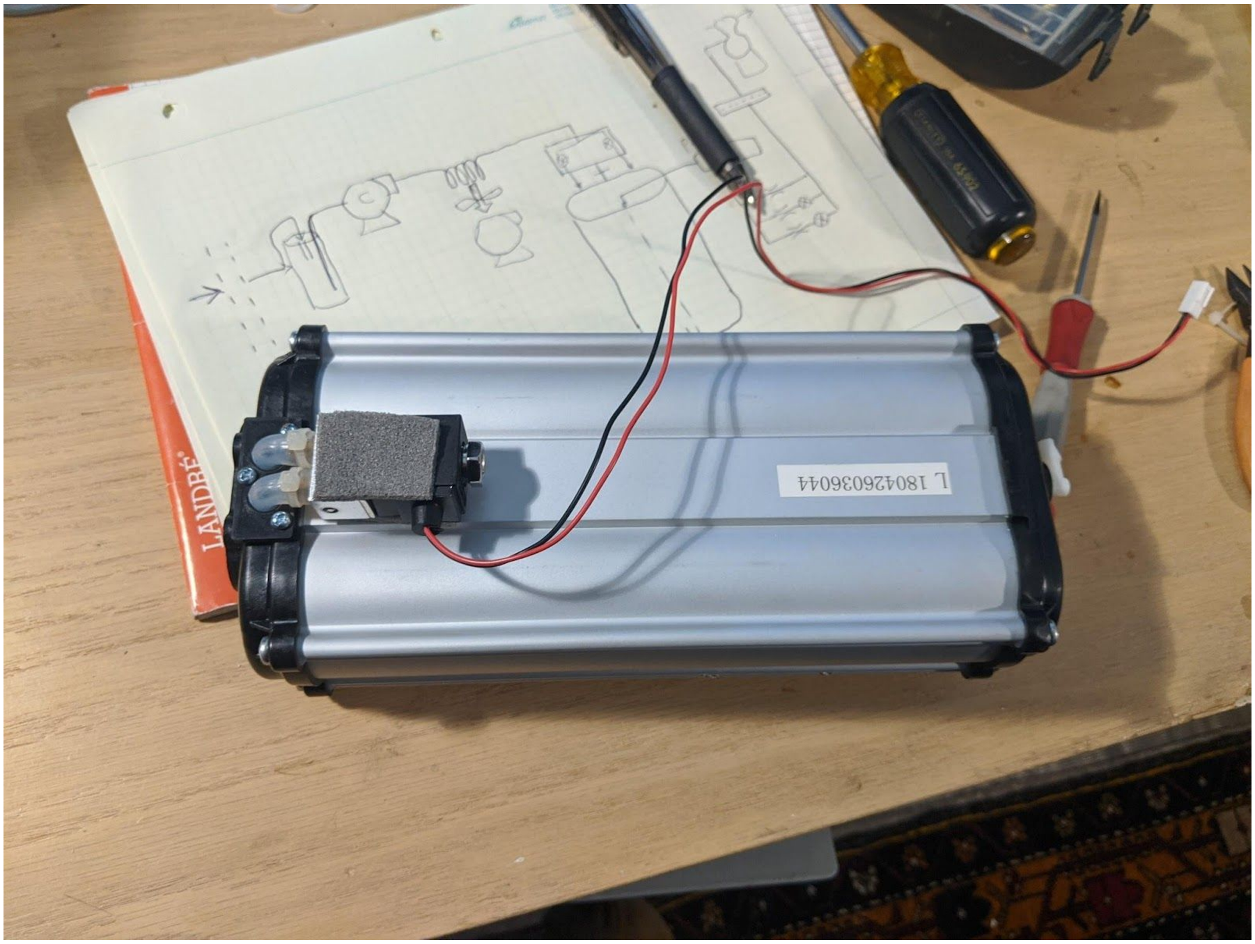


The summed outlets from the flow restrictors are passed through the final patient safety outlet filter, and then through the humidity bubbler, and finally to the patient

I have NF idea of why there's a 6kV negative ion generator with its electrodes kind of sticking out near a corner…

Adsorption assembly teardown

Now, let’s see about this dual adsorption column…

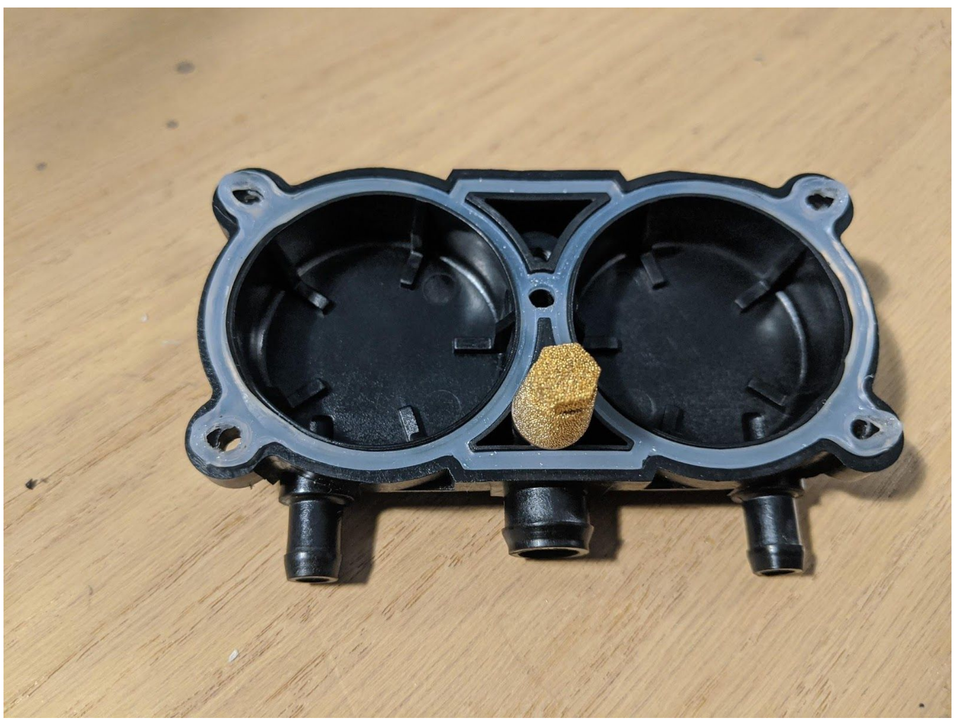


Two columns, 200mm long x 45mm diameter

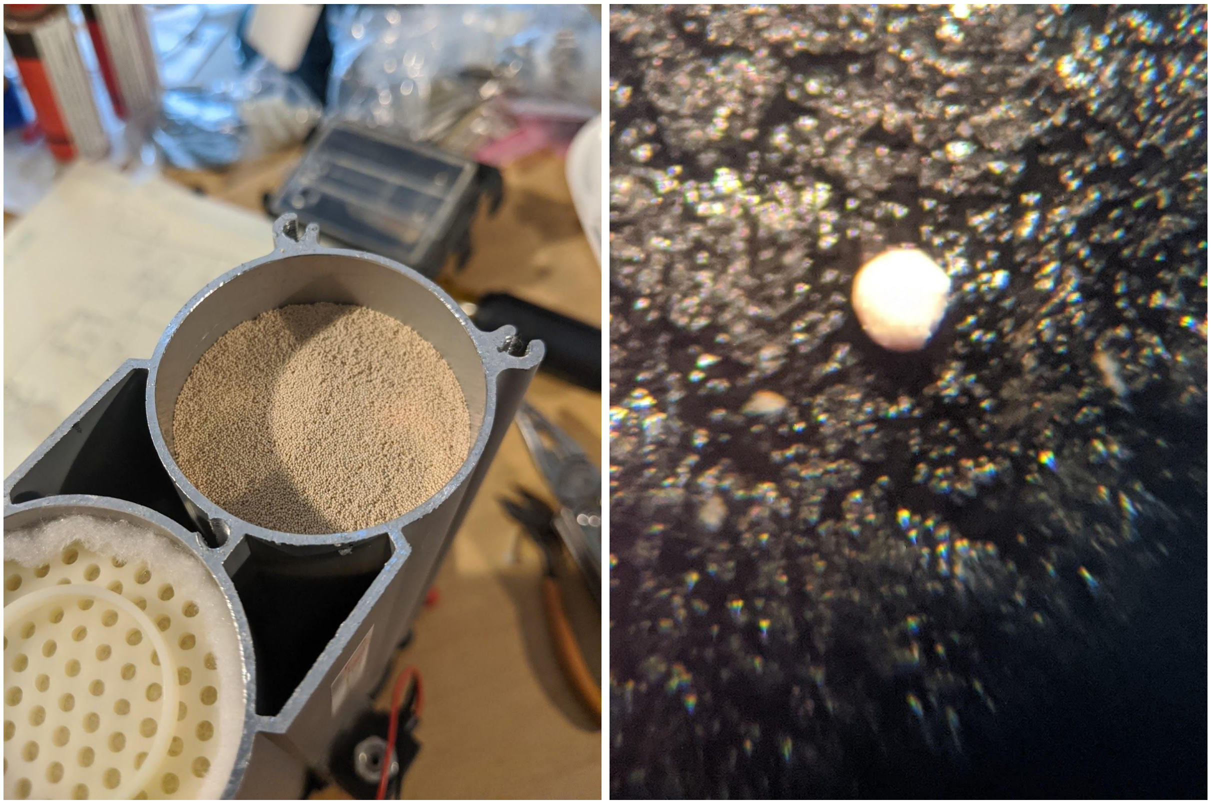
Top view, showing inlet A, inlet B, outlet, and a weird exhaust input from the valve

Bottom view, showing a two-port valve and a weird manifold

Top removed. Two springs keep the zeolite compacted



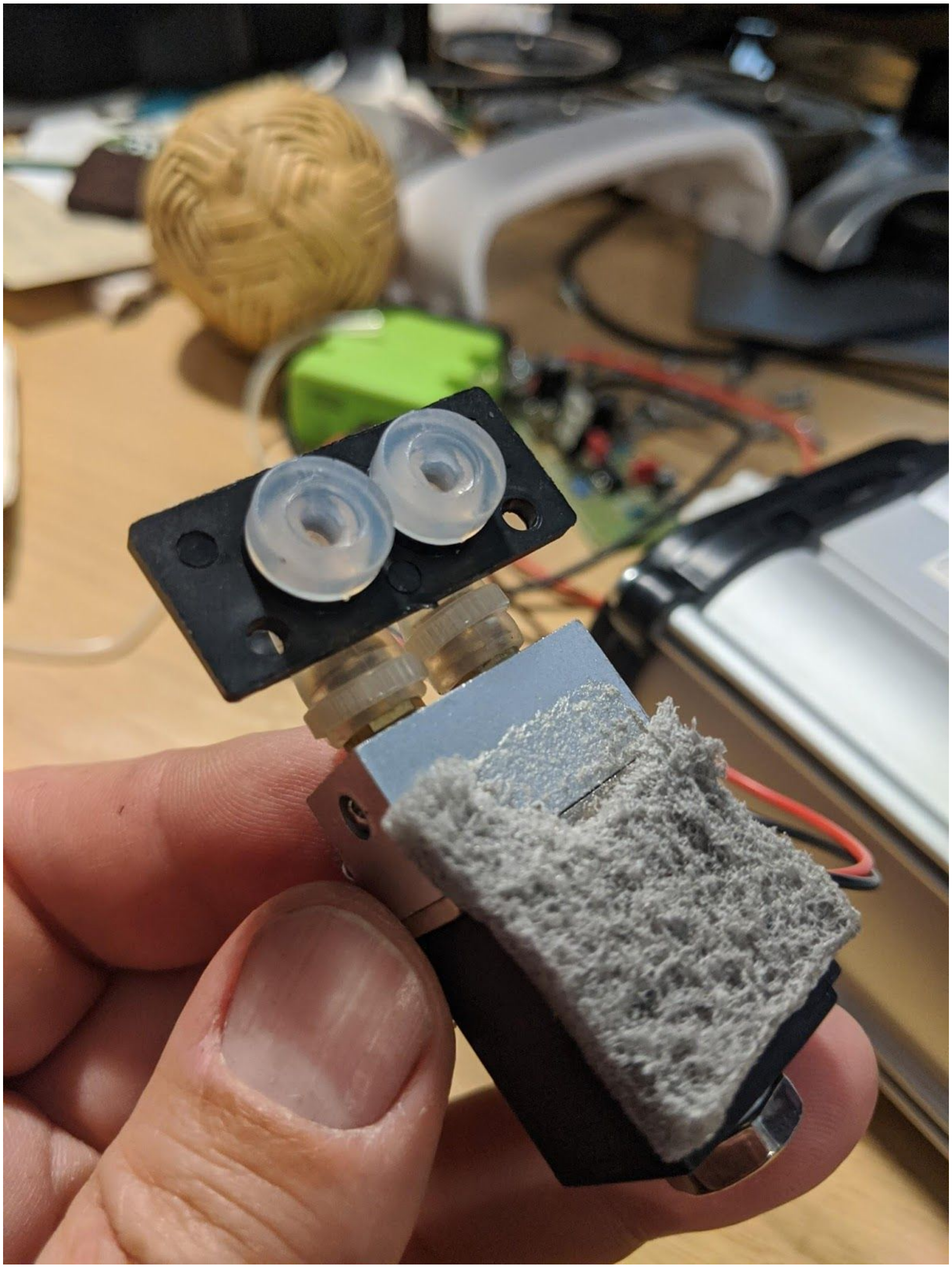
The two column inlets are trivial. The weird exhaust inlet goes through ANOTHER sintered muffler, and then into the extrusion. It exits through a hole drilled in the side of the extrusion, into the compressor cavity. Totally unnecessary for an emergency unit. Note, however, the top triangle in the extrusion leads to the outlet port. This will be important later.



Molecular sieve grade (13X) zeolite. Not your average fish tank zeolite :-(The granules are nearly spherical, off-white in color, and all pretty uniform size, at around 0.25mm diameter. From my reading, this is about a size 50 or 60 screen

Investigating the weird manifold at the bottom, we find two cavities. One has a pair of series flow restrictors, linking the bottom of the two columns.

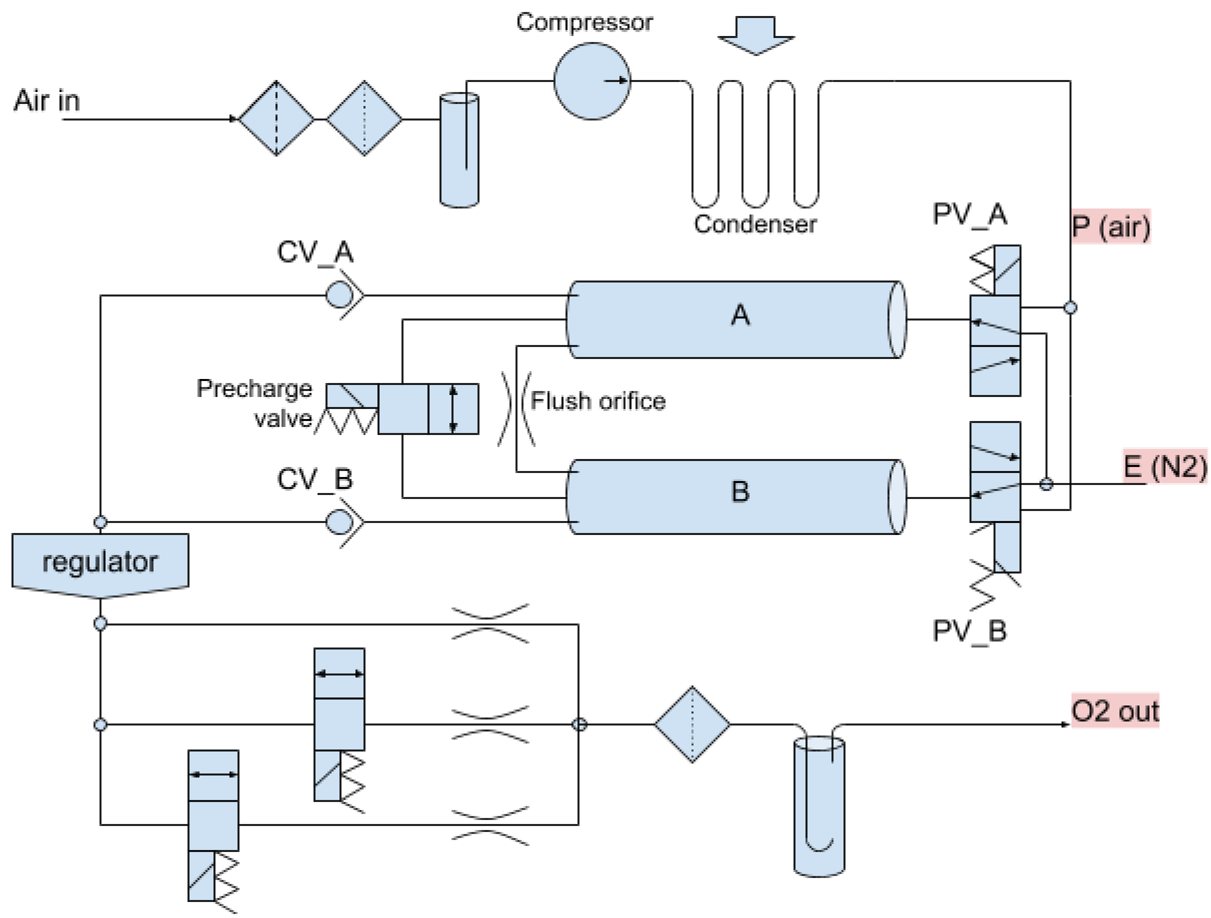
The other cavity has two check valves, both feeding the bottom (output) of both columns up into the triangular cavity in the extrusion. It exits at the top (remember that?)



This is a simple two-port on/off valve, that links the bottoms of the two columns when it opens. I call it the "precharge" valve, for reasons I will explain in the next section.

Discussion

Pneumatic flow diagram

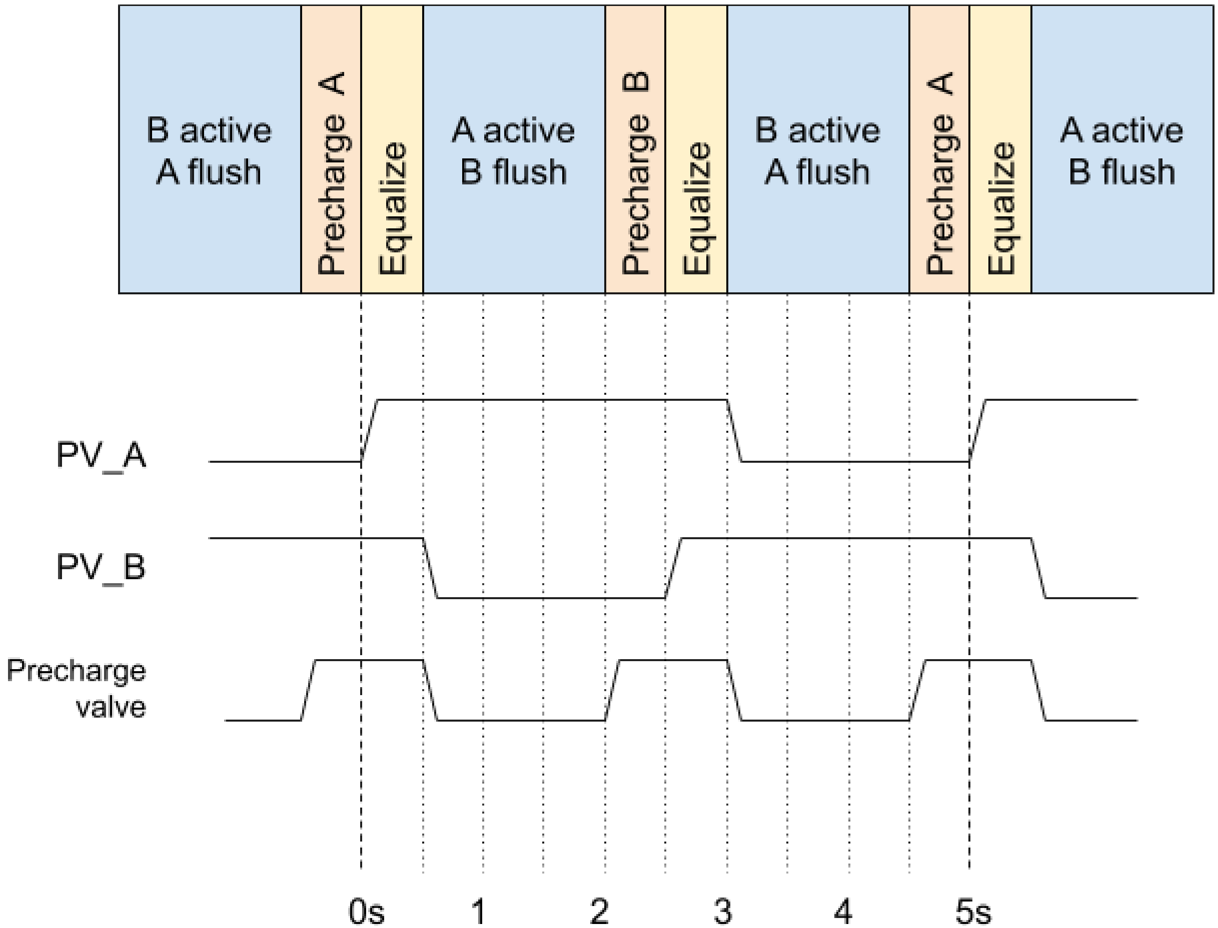


Pneumatic flow diagram. The first line shows the prefilter, the HEPA filter, the inlet muffler, the compressor, and the drier (condenser). The second line is the pressure swing adsorption assembly. The third line is the flow adjust valve bank, the outlet filter, and the humidifier.

Theory of operation

The two inlet filters, the muffler, the compressor, and the condenser supply high pressure air to the Pressure Swing Adsorption assembly.

The valves of the Pressure Swing Adsorption assembly are driven as follows:



The timing diagram

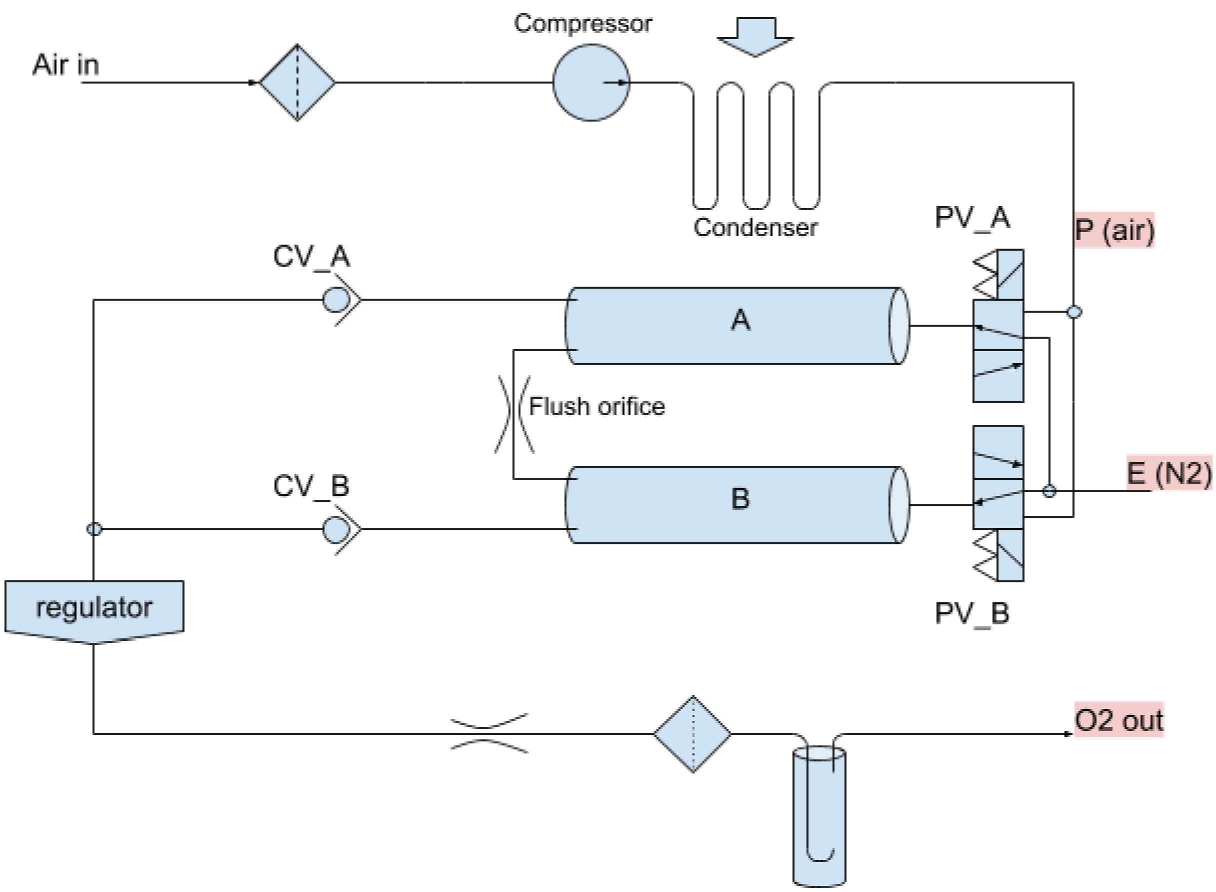
I believe what's going on is as follows:

- As cylinder A is active, cylinder B is backflushing with purified O2 from cylinder A, via the flush orifice and the exhaust port of valve PV_B .
- Just before changeover, cylinder B (that is being backflushed) is pre-charged (again from the back end) with high pressure O2 from cylinder A, via the precharge valve.
- Both cylinders are active for a brief period (½ second). I *think* this might be just to smooth out pressure at the output of the PSA assembly, to avoid flow dropouts in the output.
- The changeover happens: Cylinder A is cycled from Pressure to Exhaust. Now, cylinder B is active, and cylinder A is being backflushed.

Finally, the pressure regulator provides a constant reference pressure for the flow adjust valve bank. Each orifice permits approximately 1 liter/min of flow, so the flow is adjustable from 1 to 3 liters/min.

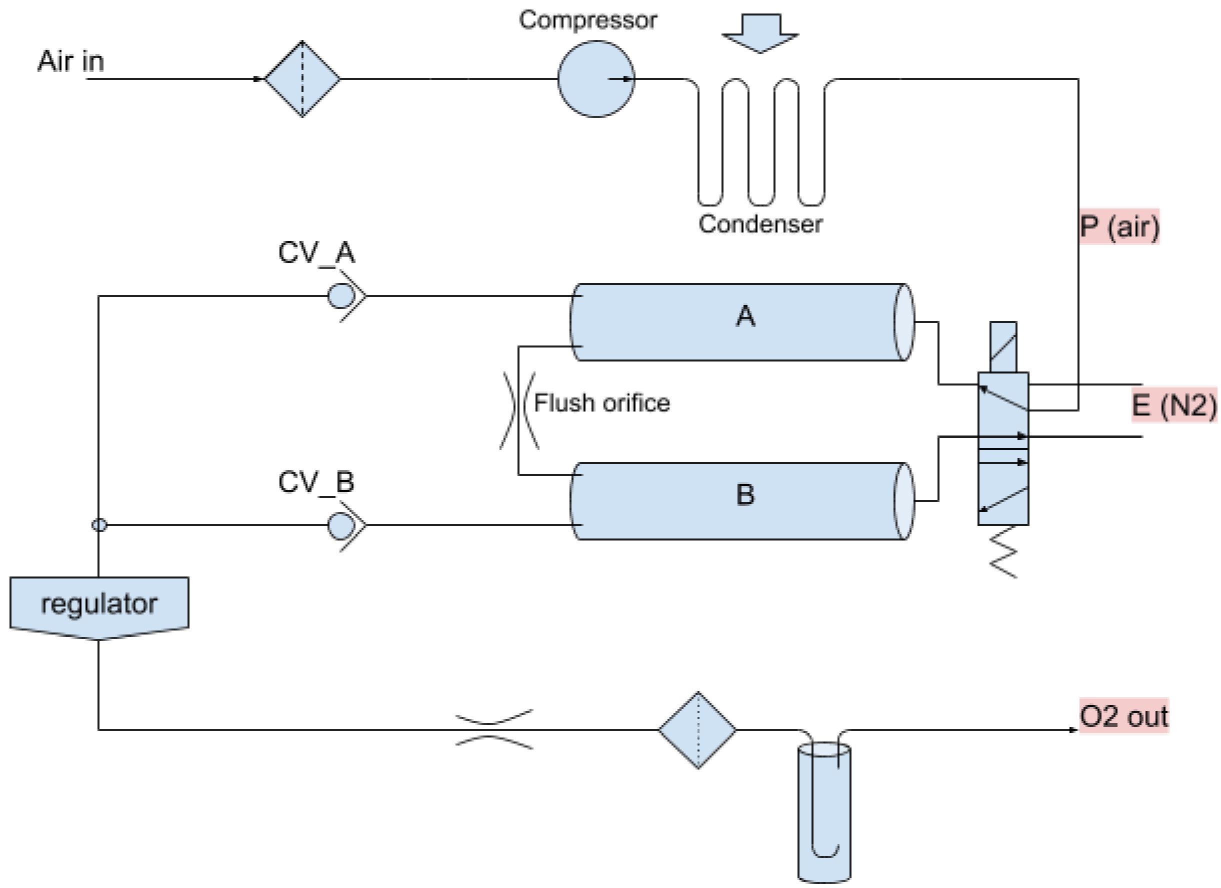
A minimal system for emergencies

I believe one could eliminate the precharge valve without issues. And as well, if one is not bothered with conserving the molecular sieve media for the long term, one could do without the flow adjustment valves. Obviously, the patient outlet filter is critical for safety. So, a minimal system might look like:



Simplified version, omitting precharge and output flow control

If one has a supply of so-called “5-2 valves”, which are made for manipulating a double-acting pneumatic cylinder, one could further simplify as shown:



Ultra-simplified version, using a single solenoid valve

Sizing a minimal system for use with Covid-19

I have read somewhere that 50 liters/min is the desired O2 flow for Covid-19 patients. If this is absolutely necessary, that has obvious and severe implications for system sizing.

On the other hand, it is possible that something is better than nothing. Medical feedback is welcome.

Fritz Stephan GmBH is mentioned in Wikipedia as supplying 240 liter/min medical grade O2 concentrators in a container format, for use in hospitals and emergencies.

It does appear that many companies offer large-scale oxygen concentrators for industrial use. Perhaps with output pressure and flow regulation, and medical grade filtration, these could be adapted for rooms full of patients in parallel.