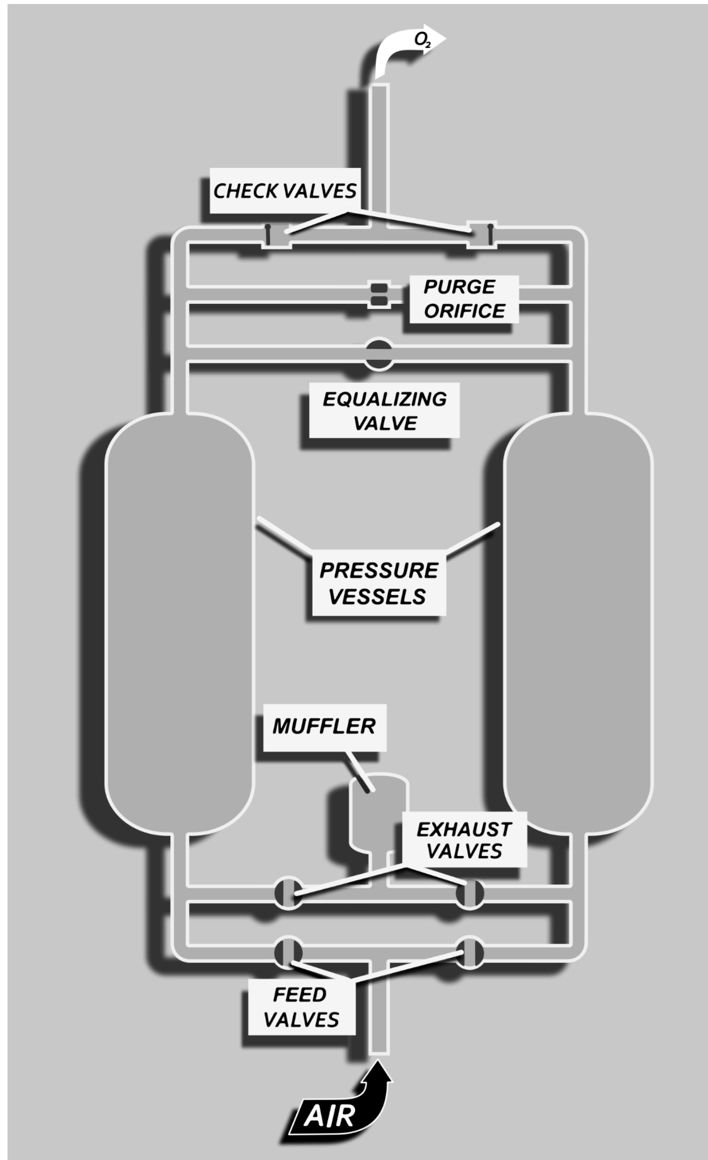
PSA Plant Cycle

Last Updated: June 26 2024

At first glance a PSA may look like a complicated Tangle of pipe, valves, and pressure vessels. With a basic understanding of the pressure swing adsorption process, however, we can begin to straighten out this tangle of pipes. By building the PSA plant one piece at a time will soon come to understand the finer points of the PSA cycle but also the purpose and function of its parts.

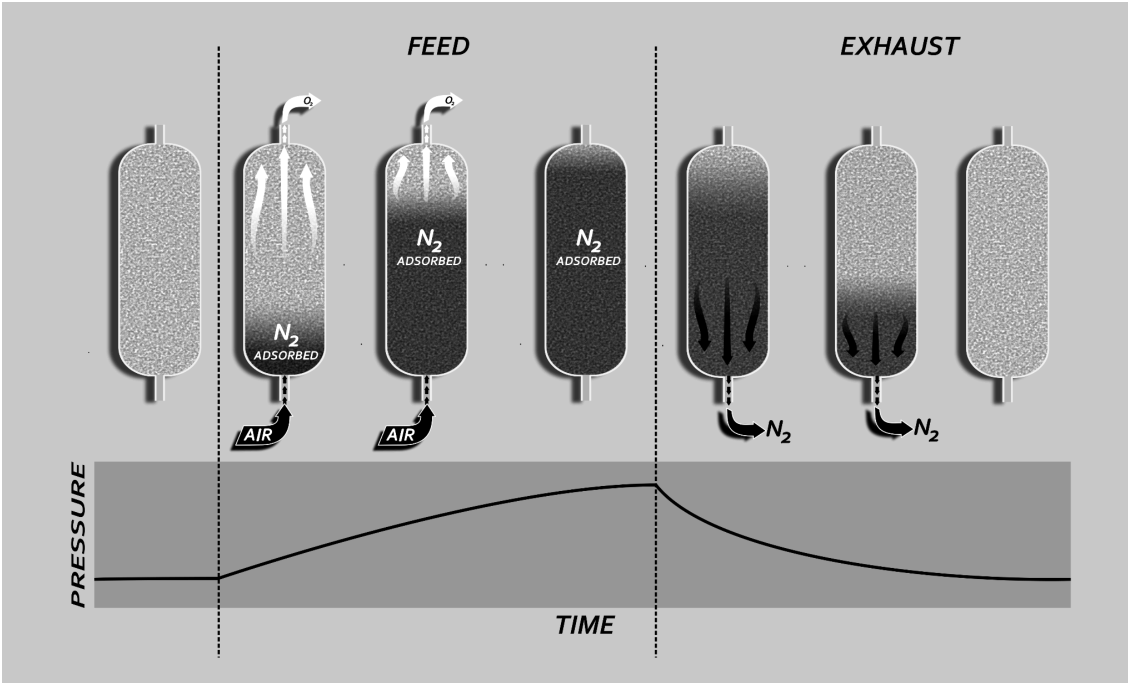


AIR SEPARATION:

PSA systems produce oxygen by separating it from air. More specifically they produce oxygen by removing the nitrogen from the air leaving high purity oxygen. Ambient air consists of roughly 78% nitrogen, 21% oxygen and 1% argon and other trace gasses. If all of the nitrogen is removed from the air the gas left over is 21 parts oxygen and 1 part argon(and other trace gasses). That is to say the gas left is 21/22 pure which is approximately equal to 96% oxygen. 96% purity is the rough upper limit of a PSA plant in general; some PSA's are capable of delivering 93% +/- 3% purity.

PSA system removes nitrogen from the air by passing the air through a pressure vessel packed with a small grains of a man made material known as zeolite[1]. As air flows through the small grains, nitrogen in the air sticks to the surface of the zeolite.   This "sticking to the surface," is known as adsorption. The amount of nitrogen adsorbed on the surface of the zeolite partly depends on the pressure of the air in the zeolite. At higher pressures, the zeolite can hold more

[1] There are many different types of zeolites, some occurring naturally.

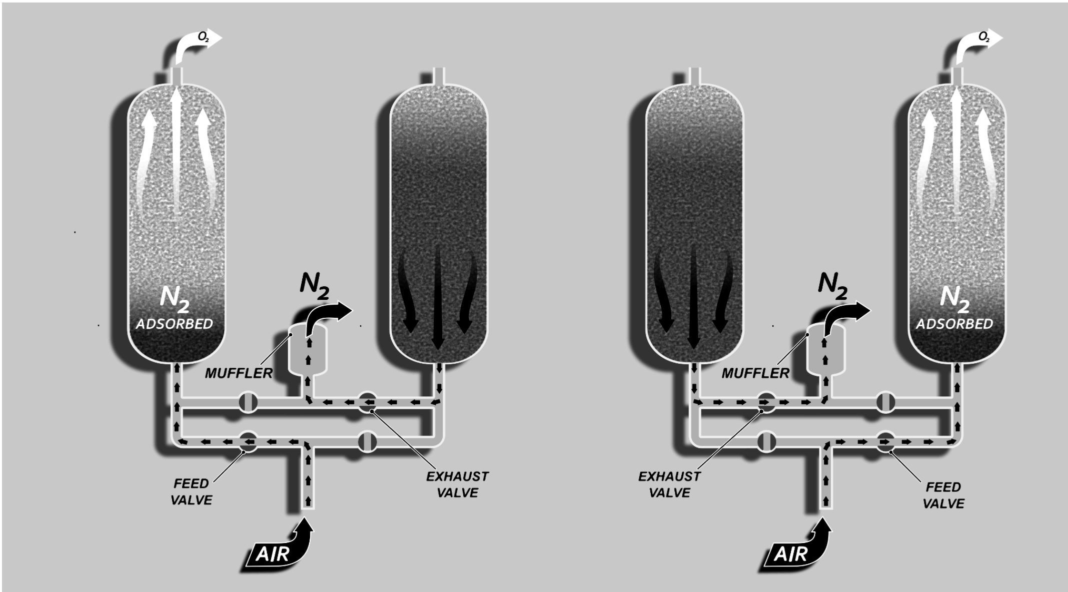


nitrogen. However at any pressure there is a limit at which the zeolite will not adsorb more nitrogen.

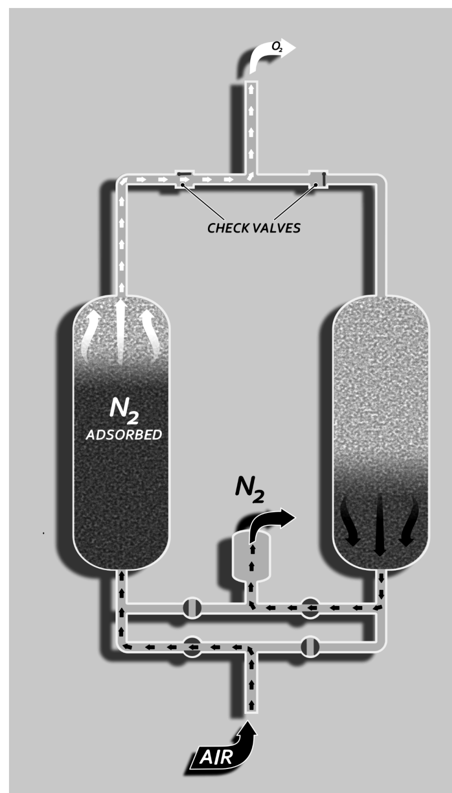
Let's look at what happens if we flow air through a pressure vessel filled with zeolite. We start with the pressure vessel at or near ambient pressure. As air flows into the zeolite, nitrogen from the air will start to adsorb onto the material of the zeolite while oxygen and argon will pass through. By the time oxygen reaches the top of the sieve bed nearly all of the nitrogen will have been removed from the air stream: high purity oxygen will be exiting the pressure vessel. Air is continually fed into the pressure vessel at such a rate that, despite the oxygen leaving the vessel, the pressure in the vessel is increasing. As pressure builds the zeolite is able to adsorb more nitrogen.

There is a limit to the amount of nitrogen that can be adsorbed by the zeolite so as more air is flowed through the vessel, some of the zeolite will become saturated with nitrogen. This is represented as the dark area of the zeolite in the figure above. After a certain time enough zeolite has been saturated that it can no longer absorb more nitrogen. No more high purity oxygen can be produced.

To produce more oxygen we need to get rid of the nitrogen that has adsorbed on the zeolite. Because the tank is at high pressure, we can remove this zeolite by exhausting the tank to the ambient environment. As the pressure in the tank drops, more zeolite will desorb from the zeolite and be exhausted. Once the tank has reached ambient pressure the cycle can repeat.



It is hopefully clear now why the process is called **pressure swing adsorption: adsorption is the fundamental mechanism to trap nitrogen, and the change in pressure "pressure swing" is used to control the adsorption and desorption**. Of course this is just one isolated pressure vessel using the simplest pressure swing cycle. In practice, such a system would likely not generate a high enough purity of oxygen for medical use. To make a more efficient plant capable of producing high purity (like what is shown in figure 1) we'll need to add some components.



BUILDING A PLANT:

Let's build a modern PSA so that we can better understand the PSA plant and the PSA cycle. We'll start by adding a second pressure vessel filled with zeolite, or as they are commonly referred, sieve bed[2]. Adding a second sieve bed allows the output of the system to have a more consistent output. By staggering the cycle, one sieve bed will be producing oxygen while the other sieve bed will be exhausting nitrogen.

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[2] The "sieve" in sieve bed comes from the term "molecular sieve." Molecular sieves are a group of materials with regular microscopic pores that can be used to separate molecules of different sizes.

To achieve this staggered cycling we must add **four "solenoid[3]" valves: two feed valves and two exhaust valves**. In general when a feed valve on one side and the exhaust valve on the other side will be open at the same time. The opening and closing of these valves is controlled by the PSA plants PLC (Programmable Logic Controller). Notice that the nitrogen from both tanks exits through an exhaust muffler. Likewise the compressed air is supplied from the same inlet pipe on the bottom of the manifold.

Like the compressed air input, we need to combine the oxygen output from each tank. We cannot, however, just join the top of the two sieve beds together with pipe. Doing so would allow the oxygen from the producing sieve bed to exit out the exhausting tank. To prevent this, we will use two **check valves**. Check valves are one-way valves, they allow gas to flow in only one direction. Here they are oriented to ensure that oxygen only leaves the top of the sieve bed. Note that check valves are not controlled by the PLC, they are passive components. While we could use two solenoid valves to accomplish this same directional control of the flow, (in fact some plants do), check valves are more common due to the reduced cost and simplicity.

So far, we have seen the adsorbed nitrogen being removed from the sieve bed by exhausting the high pressure gas out the bottom of the bed. While this would remove the vast majority of the adsorbed nitrogen, some nitrogen would remain in the sieve bed at ambient pressure. When the sieve bed started its feed cycle, some of this nitrogen would exit the top of the tank lowering the purity of the output oxygen. To achieve high purity oxygen, we need to remove this nitrogen from the sieve bed. We can do this by using some oxygen to flush out the nitrogen from the sieve bed when it is exhausting. This is known as purging.

[3] "Solenoid valve" is used loosely here to refer to any valve that is controlled by the PLC.

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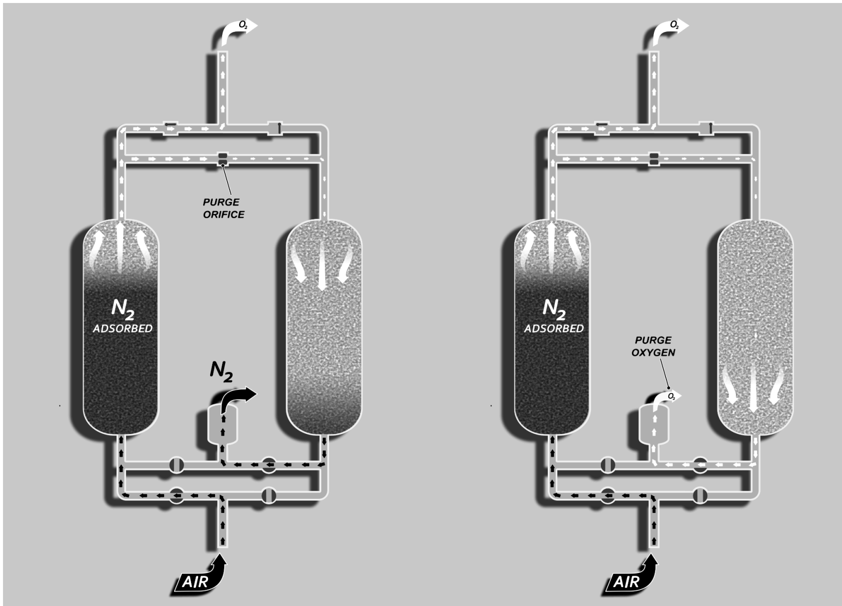


To purge the tank we connect the top of both sieve beds to each other with the "purge line." The purge line contains an orifice, a plate or plug with a small precise hole in it. The orifice restricts the flow between the two tanks to control the amount of oxygen used for purging. Notice that the orifice is a passive component like the check valves. Unlike the check valves oxygen can flow in either direction. The direction is determined by the pressure difference between the sieve beds. Thus the producing sieve bed is always providing purge oxygen to the exhausting sieve bed.

It is important to highlight that much of the purge oxygen is exhausted out of the muffler as the nitrogen is flushed. The purge line may seem to be in direct opposition to the function of the check valves: the purge line is wasting oxygen and hurting the PSA's plants yield[4]. In a sense this is true; however, it is a trade that must be made to achieve high purity.

The final piece we will add to complete our PSA plant is the equalizing valve. The valve greatly improves the energy efficiency of the cycle (cite). So far we have shown that the exhausting sieve bed exhausts from full pressure to ambient pressure. In doing so all the work in compressing the gas in the sieve bed is wasted. The equalizing valve helps us save some of this energy by equalizing the pressure between both tanks before the feed and exhaust valves switch sides. For example, assume the right side is producing and the left side is exhausting/purging. Before

[4] "Yield," here means the flow rate of oxygen leaving the product line.

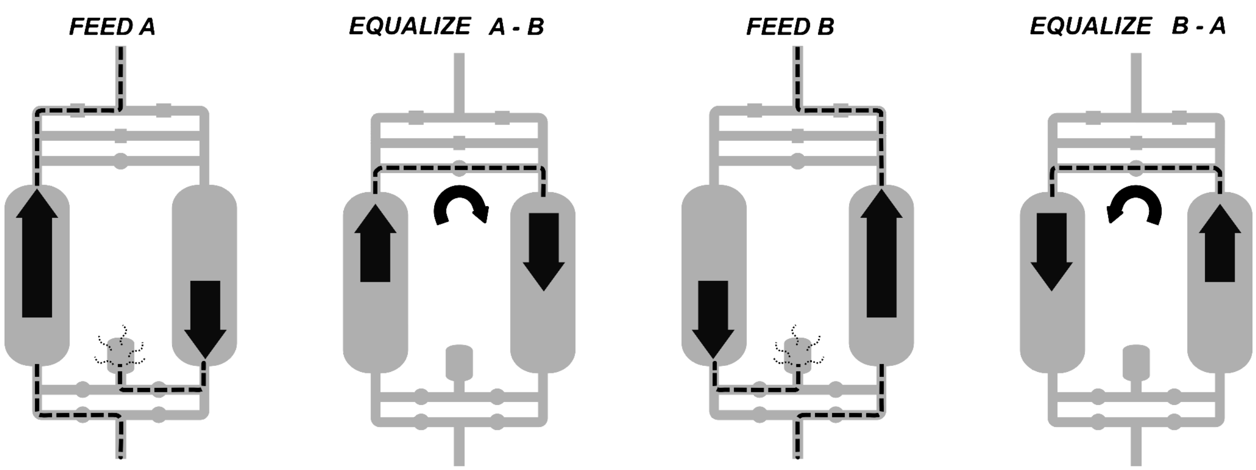
the right sieve bed is completely saturate the feed and exhaust valves[5] close stopping production. At the same time the equalizing valve opens connecting the tops of both sieve beds. Oxygen rich gas from the top of the right sieve bed rushes into the left sieve bed. After a very brief period, the pressures in the sieve beds will be approximately equal and the equalizing valve will close. Now the PSA switches sides. The right exhaust valve opens and the left feed valve opens.

In addition to saving energy, the equalizing valve helps jump start the adsorption process by raising the pressure of the sieve bed.

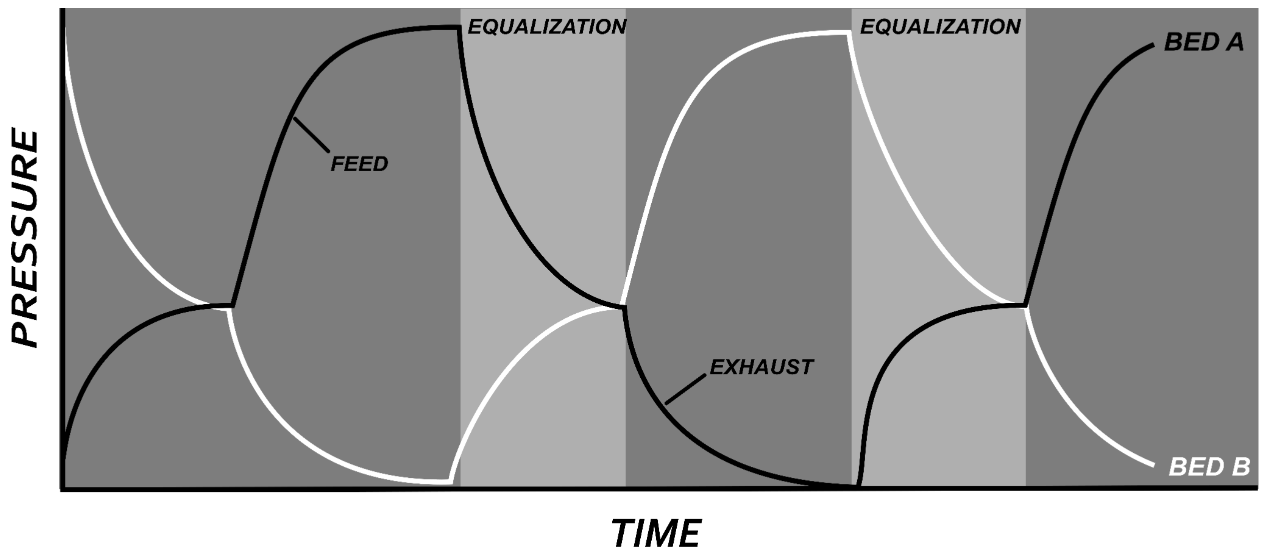
THE FULL CYCLE

Having seen all the valves let's look now at the full PSA cycle for our modern PSA plant. The cycle has four distinct stages:

1. Feed bed A exhaust Bed B
2. Equalize beds A to B
3. Feed bed B exhaust Bed A
4. Equalize beds B to A



[5] Some systems will only close the exhaust valve, others will close the exhaust valve but open both feed valves. The exact timings and stages vary by manufacturer. For simplicity in the explanation, we close both the feed and exhaust valves.



Looking at the graph above, we can see these stages. Each of these stages are associated with the opening and closing of solenoid valves. These valves are controlled by PSA plants PLC. For virtually all PSA plants the switching is executed at preprogrammed time intervals set at the factory. Pressure, input flow, output flow, output purity, etc., may be measured by the PLC, but they do not change or modulate when the PSA switches stages in its cycle. Some measured values, like oxygen purity, may halt a PSA plant's operation if it is too low, it will not change the cycle time.

The timings of a PSA plant are set by technicians at the factory. The timings will vary slightly from machine to machine to optimize their performance. In general the larger the PSA plant is, the longer a full cycle will be. For units producing only 10 LPM, the full cycle may be a matter of seconds. For larger plants producing hundreds of liters per minute a full cycle can take minutes. This becomes important because when PSA plants first start it takes several cycles to build up purity. For small machines this can happen quickly, while for larger machines this can take over an hour.