Air Products
Vacuum Swing Adsorption
VSA (VPSA) White Paper
The Process

Oxygen generation through vacuum swing adsorption systems has a long history in the industrial gas market. The feed for any oxygen generator is air which contains 21% oxygen and the balance nitrogen with a few other impurities. The goal of the O₂ VSA process is to efficiently capture the nitrogen and other contaminants while allowing the O₂ to pass through unencumbered where it will be delivered as the final product.

The VSA (VPSA) system runs as a continuous cycle comprising four main cycle steps:

1. **Air pretreatment and pressurization**
2. **Adsorption of nitrogen and other contaminants**
3. **Desorption via vacuum**
4. **Oxygen product delivery**

This is repeated cyclically between 2 or more vessels to create a constant flow of oxygen to the application where it is needed. The O₂ VSA generator works at ambient temperature, significantly reducing power consumption and capital investment in the equipment relative to the cryogenic process.
Key to the adsorption process is the zeolite molecular sieves, held in the adsorber vessels, that selectively uptake nitrogen and allow oxygen to pass through the vessel and on to product delivery. The selection and layering of the proprietary sieve materials, and their loading methods can all be optimized to achieve the most efficient and cost-effective separation of oxygen. The diagram below in Figure 1 allows for a visual walk through of system.
Air is filtered to remove particulates before it enters the feed air blower and is introduced to the adsorber vessels. Using a blower is a more energy efficient means of generating oxygen as compared to a compressor and if higher oxygen delivery pressures are required at the site of the application a smaller, more cost-effective product O₂ blower or compressor can be added to the system to achieve the desired final outlet pressure.

After the air blower, the air passes into an adsorber vessel loaded with layers of molecular sieve to adsorb the nitrogen and allow the oxygen to pass through at purities between 90-94% O₂ with the remainder being inert argon and trace levels of N₂. Once the molecular sieve is fully saturated with N₂, the air feed is switched to the next vessel which is ready to adsorb additional nitrogen. This method, with a buffer vessel, allows for continuous oxygen supply at the process endpoint. Once a vessel has fully adsorbed nitrogen and the process feed is switched to the next one in line, a vacuum blower reduces the pressure of the fully saturated molecular sieve to effectively desorb the nitrogen and other contaminants to regenerate the materials and prepare them to receive fresh feed air supply. The waste nitrogen is typically vented back into the atmosphere resulting in an environmentally friendly process.

In the industrial gas industry, there are two primary technologies employed for the production of O₂ for customer needs – each right-sized for customer needs. The key points in selecting a O₂ VSA system versus a cryogenic air separation plant are typically purity, flow and the types of industrial gases that need to be produced. These are shown in Figure 2 below.

**Figure 2: Oxygen Generator Specifications**

<table>
<thead>
<tr>
<th>Unit of Measure</th>
<th>Vacuum Swing Adsorption (VSA)</th>
<th>Mid Cryogenic Oxygen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>700 to 30,000 O₂</td>
<td>N₂: Up to 37,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O₂: 3,000 to 18,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N₂: Up to 1,090</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O₂: 100 to 600</td>
</tr>
<tr>
<td>Pressure</td>
<td>90% to 94%</td>
<td>N₂: 99.999%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O₂: 99.6%</td>
</tr>
<tr>
<td>Purity</td>
<td>25 to 300 O₂</td>
<td></td>
</tr>
<tr>
<td>Footprint</td>
<td>Smaller</td>
<td>Larger</td>
</tr>
<tr>
<td>Installation Schedule</td>
<td>Shorter</td>
<td>Longer</td>
</tr>
</tbody>
</table>

Comparison of VSA (VPSA) oxygen generation with cryogenic oxygen generation:

- Both systems provide power efficient gas supply to produce the lowest cost gas possible
- A skidded design for scalability and low installation cost is utilized for O₂ VSAs and cryogenic ASUs
- At higher oxygen flowrates and higher O₂ purity, the economics shift towards cryogenic systems
Additional configurations

**Radial Flow Bed Adsorption**

One of the key evaluation points for oxygen generation is power consumption. The less power required to produce each Nm3 of oxygen the more cost effective the entire system will be and the greater the value added to the end application. The main purpose of the radial adsorber is to reduce the pressure drop and increase the adsorption performance with a relatively compact structure, which typically results in long-term energy-savings, especially for larger systems and higher oxygen flow requirements.

**Patented Modular Bed Technology**

The adsorption and desorption O2 VSA (VPSA) vessels with both parallel and single bed configurations, of the patented modular bed technology, show that better adsorbent utilization is achieved in the parallel vessel configurations due to reduced feed velocities. This increases the total amount of time a vessel can be online before nitrogen has fully entrained the bed and the system experiences breakthrough. Air Products’ parallel flow design maximizes these benefits and are installed in various applications around the world, including wastewater, pulp and paper, smelters and glass manufacturing locations.
Additional factors to consider

In addition to lower operating costs, power consumption and footprint companies want to consider ease of long-term operation, maintenance and reliability when making their purchasing decisions. Most oxygen VSA systems come standard with remote monitoring and operational capabilities, simplified and quick startup and shutdown routines and other features to increase overall reliability. O$_2$ VSA systems can also be designed with built in redundancies in equipment or with a liquid oxygen backup tank in mind to assure that the end process always has oxygen when it is needed. Oxygen product delivery pressures can be customized to each application’s unique requirements and if burner technologies are involved, specialty application engineers can sit with the system designers to further customize the oxygen delivery to the process.

There is a reduction of environmental emissions of NOx when using a VSA (VPSA) system since the impurities in the O$_2$ product stream is a majority argon, with very little nitrogen left to react and form NOx at the oxygen use point.
Conclusion

As with many decisions in the business environment, there are multiple points to evaluate oxygen production on. This paper has highlighted some of the key drivers that should be taken into consideration. As companies continue to look for optimal ways to enhance their processes with oxygen, the vacuum swing adsorption system will continue to play a key role in the future.
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