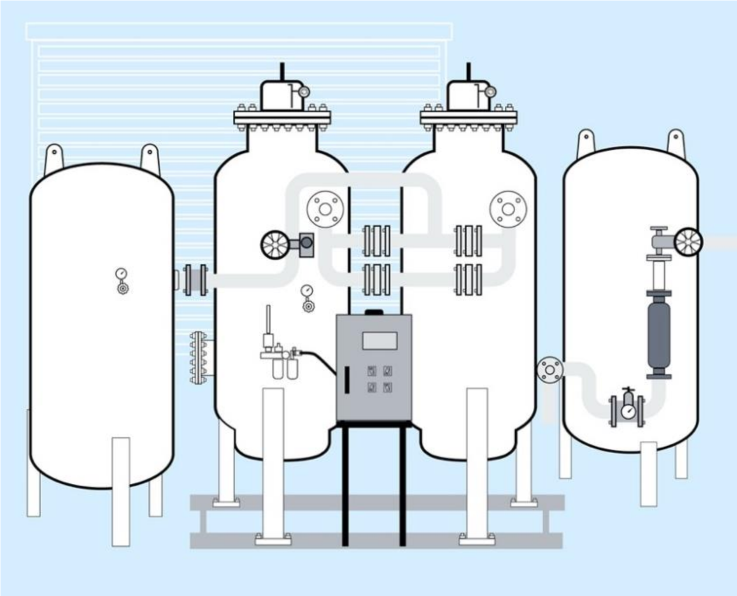
FOR: DECISION-MAKERS

SUPPLY INTELLIGENCE

Oxygen Generation and Storage: Pressure/Vacuum Swing Adsorption Plant

Technical overview



Oxygen can be generated by using pressure swing adsorption (PSA) technology, which concentrates oxygen from ambient air. In this process, the air is dried, and impurities, such as carbon dioxide, hydroc/arbons, and water, are removed. The air passes into pressure adsorption vessels fitted with interconnecting valves that house zeolite material—a porous mineral containing aluminum and silicon compounds—that preferentially adsorbs nitrogen while allowing oxygen to pass through. Once the zeolite is saturated and the oxygen collected, the pressure in each adsorption vessel is reduced (swinging from high to low), and the nitrogen is released to allow more air to be treated to produce oxygen using the same zeolite. An on-site PSA plant can supply high-pressure oxygen throughout a hospital via a central pipeline system or cylinders filled at the plant.

Vacuum swing adsorption (VSA) technology also uses a zeolite sieve for separating the oxygen and nitrogen, but plants utilize a vacuum blower instead of an air compressor and a smaller number of adsorption vessels and valves. These systems are more energy-efficient, have lower operating costs, and can operate at higher altitudes without a reduction in performance, but typically have a higher upfront capital cost than a comparable PSA plant. They also produce oxygen at a much lower pressure than a PSA plant and often require an additional high-pressure oxygen compressor to boost pressure to meet needs of health facility piping networks. When selecting either a PSA or VSA system, irrespective of the technology, it is most important that the tender includes robust technical and performance requirements based on the intended use case and location.

Key specifications

PSA and VSA plants can vary in size and capacity, but basic specifications include oxygen production purity at 93% ±3% and continuous output pressure of 50 to 55 pounds per square inch gauge (psig) (US NFPA 99: Health Care Facilities Code) or 400 to 500 kilopascals (kPa) (ISO; piping only). They are designed for a minimum life span of 10 years and should be capable of supplying the specified oxygen concentration continuously in ambient temperatures from 10°C to 40°C, relative humidity from 15% to 95%, and elevation from 0 to at least 2,000 meters. A PSA/VSA plant should include audible and visual alarms in the event of power failure, system failure, or when oxygen concentration falls below 90% purity. For a conventional PSA plant, the nominal flow rate ranges from 8 to 2,500 liters per minute (LPM) (0.5 to 150 normal cubic meters per hour [Nm^3/h]) at 50 psi. VSA plants can achieve nominal flow rates of 52 to 3,155 Nm^3/h at 5 psig (34.5 kPa).

Regulatory considerations

PSA and VSA plants should have European certification (CE marking) or other stringent regulatory authority approval. Relevant guidelines include ISO 7396-1 and/or US/European Union pharmacopeia compliance standards for oxygen at 93% production purity. Registration with local health authorities may be necessary if distributing cylinders outside the facility.

Infrastructure requirements

PSA/VSA plants all require electricity and sufficient ambient air flow. For electricity, a continuous and reliable source of power, ideally 230V single-phase (for VSA and valve operations) and 380V–400V three-phase power at 50 Hz (for PSA and compressor/dryer operations), is necessary. Although there can be notable variation, a conventional PSA plant requires approximately 1.2 kilowatt hours (kWh) per Nm^3 produced at 65 psig, depending on system efficiency and oxygen service pressure. For a VSA plant, approximately 0.39 kWh per Nm^3 of total flow at 2.7 psig is necessary, depending on system efficiency. Energy consumption will increase for higher service pressures and if cylinder filling is required.

For operational requirements, certain environmental conditions must be met, such as air conditioning, roofing, and a proper ventilation system to ensure clean air intake for breathing; also, the designated area must not have flammable products present. The equipment generates substantial amounts of heat and requires adequate air conditioning for cooling. A PSA plant, if skid-mounted, should be in a well-ventilated housing, for security and protection from adverse weather conditions.

To note, PSA/VSA plants are also commonly configured with medical oxygen piping. Hospital pipeline systems typically supply oxygen at higher pressure to equipment such as anesthesia machines and ventilators. These systems eliminate the need for transporting heavy cylinders between hospital wards and should be composed of type L copper tubing and brazed copper fittings. A backup supply (e.g., cylinders) is required to maintain oxygen flow in case of a power outage or mechanical failure. In lieu of piping, some hospitals will instead use a compressor and fill cylinders for local use.

Supply/shipping

Depending on size, customization, and supplier's capacity, production lead times range from 2 to 24 weeks. In addition, depending on the port of origin and final destination, 2 to 12 weeks of shipping lead time is required. Installation requires complex logistics to ship multiple containers from the port of entry to the final destination, and the time required to develop the installation site must be considered (and can be done in parallel). Systems may be assembled on-site or are available pre-assembled on a skid or shipping container installation. Furthermore, considerations should be made the routine maintenance and repairs, which will require a supply of spare parts. In many settings, a stockpile of manufacturer-recommended spare parts is advised to ensure interruptions remain short.

Dependencies for use

Depending on manufacturer recommendations, a compressed air surge tank and/or oxygen receiver tank, an air compressor, and a filter/drier for the air compressor may be required. In that event, it is common for PSA/VSA manufacturers to provide recommended models or specifications with additional equipment as a package. For piping, flowmeters and regulators are necessary. Other related equipment could include a high-pressure oxygen compressor, in the event that the PSA/VSA plant will be used for cylinder filling.

Maintenance

For ***preventive*** (scheduled) maintenance, a buyer/owner can contract with the manufacturer for maintenance that requires highly trained technicians and engineers. This can include cleaning or replacing filters, draining water or oil traps, replacing lubricants, and calibrating pressure and oxygen sensors. The plant operating environment should be maintained with correct ventilation and cooling. Although common, such a maintenance agreement may not always be feasible, and in such an instance, buyers should evaluate whether there are trained technicians or qualified third parties available to service the system.

For ***corrective*** maintenance, it may be necessary to rebuild a valve assembly or compressor in the event of failure. Additionally, sieve beds must be recharged periodically if there is a reduction in performance in the oxygen generating capacity or purity.

Cost

The investment costs for a PSA or VSA plant depends on size, functionality, equipment, whether accessories (or other products) are purchased, and whether the product is containerized (which would require lower plant housing costs). Generally, PSA plants require a lower capital expenditure than VSA plants, which command a 10% to 20% premium in upfront costs, and may require a compressor to feed a piped system. The improved efficiency of VSA plants, however, could allow for notably lower operating costs that balance the upfront costs quickly. As a reference, for a large hospital (greater than 1,000 beds) in east Africa requiring a total oxygen capacity of 4,114 kg per day of 93% purity, a PSA plant solution is estimated to cost US$800,000 with anticipated monthly operating expenditures of US$1,900 to cover electricity, service, and maintenance. A VSA plant for the same hospital, daily volume, and purity is estimated at approximately US$880,000 with anticipated monthly operating expenditures of US$1,000. For smaller health facilities (150 to 200 beds), a plant with suitable production volumes will be closer to US$100,000 to US$110,000. Prices may vary significantly depending on manufacturer, production volume, purity level, and other factors. In general, a CE mark or other stringent regulatory approval on a plant will add approximately 5% to the price of a new unit. It is important to research local production demands and thoroughly understand the operating requirements and associated costs of the equipment under consideration.

COVID-19 considerations

In the context of a global pandemic like COVID-19, additional considerations should be raised, including:

- PSA and VSA plants can be scaled depending on production volume needs. Smaller plants can be skid-mounted and delivered to health facilities for on-site production. Large, permanent systems can be built farther afield and oxygen from the facility can be stored in cylinders and delivered via cylinder trucks. Further, PSA and VSA plants can be configured for dual use when the plant is co-located at a health facility with directly piped oxygen supply along with a booster compressor to fill and distribute oxygen cylinders to other, nearby health facilities.
- Smaller, on-site plants are largely self-sufficient and do not require constant technician involvement, but qualified staff presence is necessary to prevent problematic outcomes.
- On-site PSA/VSA systems should ensure infection control practices are relevant to the piping system that delivers the oxygen from the plant to the patient rooms.

Acknowledgements

This brief is part of a larger series on technologies and equipment related to ***Oxygen Generation and Storage***. It is intended to serve as a concise primer for decision makers that govern, lead, support, or manage health systems and provide a starting point for understanding the solutions available to meet a health system's need for medical oxygen and its delivery.

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For more information

path.org/programs/market-dynamics/covid-19-and-oxygen-resource-library

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