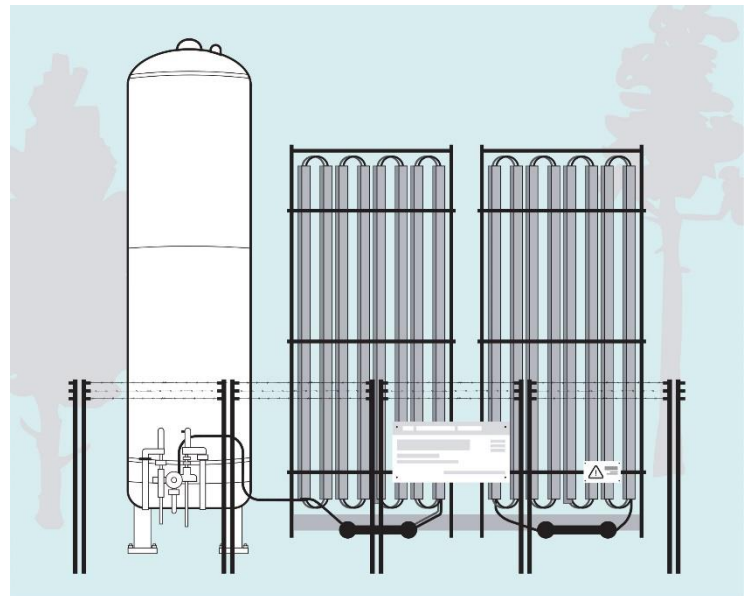


Oxygen Generation and Storage: Vacuum-Insulated Evaporator System

Technical overview

A cryogenic liquid oxygen storage tank is an insulated vessel consisting of a carbon steel outer shell and a stainless-steel inner vessel, with an insulating vacuum space between the layers to minimize heat ingress. Oxygen liquefies at -183°C at one atmosphere of pressure and is generally stored at pressures closer to 23 atmospheres. Together with vaporizers, valves, piping, and a pressure control and pressure relief system, the tank constitutes a **vacuum-insulated evaporator (VIE)**, which can supply a central oxygen piping system in a medical facility and is often leased from the medical gas supplier. Oxygen enters the piping system after passive evaporation in the vaporizer, and therefore does not require a source of power. VIEs can be configured to fill cylinders, too, without electricity. Transporting oxygen to these tanks and storing it as a liquid takes less space and is less expensive than moving and storing it as a gas under high pressure, as one liter of liquid oxygen produces 861 liters of gaseous oxygen. Although liquid oxygen is economical for facilities that use large quantities, the bulk liquid to fill the tanks is produced at a cryogenic air separation unit (ASU) and requires a specialized bulk road tanker for transport from ASU to VIE. Careful handling is required due to the possibility of accidentally rupturing the pressurized tank, which could lead to safety risks such as cold burns and a source of ignition for fires.



Key specifications

Key requirements for properly operating VIEs include:

- A cryogenic liquid oxygen tank which can be installed in a vertical or horizontal position.
- Capacity typically ranges from 500 to 25,000 liters of liquid oxygen storage for health facility use. Larger capacity units can be custom built as needed.
- The maximum allowable working pressure ranges from 1 to 37 atmospheres.
- Hold time (time between filling and the unit venting to atmosphere) for the tank ranges from 10 to 150 days, based on the manufacturer specifications and the ambient conditions.
- Flow capacities between 150 and 20,000 liters per minute, based on the vaporizer design and specification.
- Different approved fill adaptors are used for filling liquid oxygen VIEs and liquid nitrogen VIEs to prevent inadvertent cross filling.

Regulatory considerations

It is advisable to confirm with a supplier that VIEs under consideration adhere to ASME Boiler and Pressure Vessel Certification standards and ensure pressure vessel certification, as well as ISO 21029 requirements addressing the design, fabrication, inspection, and testing of VIEs. Quality management protocols should adhere to ISO 9001/2000 to ensure consistency and applicable regulatory requirements. VIEs must also comply to the following regulatory requirements:

- ISO 20421-1 for Cryogenic vessels – Large transportable vacuum-insulated vessels – Part 1: Design, fabrication, inspection, and testing
- ISO 21009-1 for Cryogenic vessels – Static vacuum-insulated vessels – Part 1: Design, fabrication, inspection, and tests
- ISO 21010 for Cryogenic vessels – Gas/materials compatibility
- ISO 21013-1 for Cryogenic vessels – Pressure-relief accessories for cryogenic service – Part 1: Reclosable pressure relief valves
- ISO 23208 for Cryogenic vessels – Cleanliness for cryogenic service

Infrastructure requirements

While a VIE itself does not require electricity to operate, its filling pumps, monitoring systems, alarms, and other safety features do. VIE and support infrastructure must be placed in a secure, fenced, well-ventilated area that is free of overhead powerlines and other potential sources of ignition, such as diesel generators. Parking and smoking must be strictly prohibited. The fenced area must be fitted with safety signage prescribed by international safety directives. The tank must be accessible by large cryogenic bulk road tankers for refills. A central pipeline distribution system with vaporizers is required, along with ancillary shut-off valves, pressure-reducing and safety valves, and pressure flow regulators. If an ambient vaporizer is used, it must have adequate airflow to absorb sufficient heat and prevent icing, although an electrically heated vaporizer is available for colder climates. The vaporizer must also be sized correctly to meet the maximum flow rate required by the medical facility. A second vaporizer is normally installed to enable continuous operation on 8-hour cycles, to minimize the build-up of ice.

Supply/shipping

For the VIE: Prefabricated vacuum-insulated tanks and vaporizers can be ordered from a manufacturer and, depending on geography, may be delivered in approximately 1 month. Preparing the site, including excavation, leveling, concrete pouring, or other activity required for the location of the VIE, should be addressed in advance. Installation, both of the VIE system and its associated piping, may take 5 to 7 days depending on the unit, site proximity, and availability of technicians. Typically, a large gas manufacturer and supplier have a range of different sizes of VIEs that can be deployed to medical health facilities, thereby reducing VIE manufacturing lead times. If sufficient infrastructure is available, the lead time from order placement to delivery for a VIE is 3 to 6 months, but for urgent applications, VIEs can be installed and be operational within 4 weeks to the medical facility. Transportation lead times depend on distance, road conditions, and availability of suitable trucks such as flatbeds.

For the oxygen generated: The liquid oxygen that is stored in a VIE is produced commercially in a continuous process from an ASU. A VIE can also be used by a bulk oxygen company as intermediate storage (e.g., when importing liquid oxygen into the country). After vaporizing the liquid oxygen, a booster compressor can be used to fill cylinders for local distribution to hospitals. Some VIEs can provide liquid-to-gas cylinder filling without the need for a compressor. Further, VIEs installed in a standard shipping container frame can be used as mobile sources of oxygen supply for field hospitals (these are commonly known as “ISO-tanks”). Shipments of liquid oxygen by cryogenic road tankers must comply with local transportation regulations of the country, and different network options are used by companies to optimize delivery. The structure of a company’s network can determine how quickly a supplier can respond to orders.

Dependencies for use

The following accessories are needed for VIE operation at a hospital:

- Vaporizer to convert liquid oxygen to gaseous oxygen.
- Piping to deliver gaseous oxygen to/through a facility.
- VIE configured to fill cylinders directly where cylinder filling is required.
- Pressure controls and pressure relief systems for safe use and operation.
- System and operation alarms.

Maintenance

VIE maintenance requires highly trained technicians or engineers. Because VIEs are leased to medical facilities and are maintained by the gas supplier, technicians and engineers for maintenance are provided as part of a gas supply contract.

Preventive (scheduled) tasks include but are not limited to cleaning grease and oil from metallic components with an appropriate cleaning solvent (such as trichloroethylene), maintaining the VIE in good operating condition, and regularly inspecting key system components. VIE inspection and maintenance tasks (which depend on the original equipment manufacturer and local regulations) generally are recommended as follows: valves and fittings must be checked quarterly for leaks and other malfunctions, level and pressure gauges must be inspected annually, relief valves to verify proper settings must be checked every two years, and the VIE bursting discs (if fitted) should be replaced every two years.

For **corrective** maintenance, plumbing must return to ambient temperature before any repair work is performed. The VIEs must be vented or drained as specified before replacing any component(s) exposed to pressure or to cryogenic liquid.

Cost

Depending on a VIE's size, installation with all required infrastructure (e.g., pipes, vaporizer, housing, and shady location) can cost from US\$10,000 to US\$100,000. Typically, facilities will enter into a leasing agreement with a service provider. Cost to lease and provide maintenance/operational service can be up to 40% of the VIE cost on an annual basis. Thus, a US\$100,000 VIE will merit a monthly payment of US\$3,330. Additional costs to install delivery technology such as pipes for transfer into hospitals or a cylinder-filling plant may need to be considered. In addition to procurement and transportation cost for liquid oxygen storage tank, operating costs include maintenance and labor.

COVID-19 considerations

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

- Liquid oxygen offers the most affordable cost-per-liter pathway to deliver oxygen to facilities with high demand and is suitable for large referral hospitals with high patient loads related to COVID-19 or acute respiratory distress syndrome. This cost benefit is realized when facilities are located close to a liquid oxygen production plant or bulk storage hub, depending on the distribution model.
- High demand for liquid oxygen delivery and subsequent increased frequency for VIE refills require logistics considerations to ensure uninterrupted service. In addition, when meeting or exceeding peak demand—as may occur during the pandemic—vaporizers that convert oxygen from a liquid to gaseous state may require additional monitoring. Higher flow volumes, particularly in humid environments, will cause ice build-up on the vaporizer (which can be mitigated by increasing the size, twinning, de-icing with water, or heating).

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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