Ultrapure water

A small cost with outsized risk in green hydrogen

By Stephen B. Harrison

Ultrapure water is a small line item in green hydrogen budgets, but a single point of failure for the entire plant.

Each kilogramme of green hydrogen requires 9 to 10 litres of ultrapure water, and any interruption in supply can force a full electrolyser shutdown. This equates to circa 200 litres of water per megawatt of electrolyser capacity per hour of operation. To generate that amount of ultrapure water, around 1.5 times as much fresh water is required.

As projects scale to multi-hundred-megawatt and gigawatt levels, the reliability and design of water treatment becomes mission-critical.

Consistent quality and reliable supply

With freshwater feed, ultrapure water systems typically account for around 4% to 8% of electrolyser plant capex, rising to 10% to 15% when desalination is included. This is a combination of dosing chemical costs and electrical power for high-pressure water pumps. Operating costs are comparatively low, generally below 1% of total plant opex, increasing to 3% when seawater desalination is required.

While these costs are modest, the consequences of failure can be very high. Reliability is therefore key. An interruption to the water supply would mean the electrolyser must shut down.

Impure water can be extremely damaging to the electrolysers. Calcium or magnesium cations in the water will rapidly damage a PEM electrolyser membrane due to interaction with the water-splitting catalyst that coats the membrane. High-temperature solid oxide electrolysers (SOEs) are also sensitive to poisons in the water.

High-temperature electrolysis integrated with ammonia production

Regardless of hydrogen feedstock, ammonia production requires significant volumes of ultrapure boiler feed water to generate steam – around four tonnes per tonne of ammonia. The water treatment technologies required are similar to those used for electrolysis.

Combining water treatment systems across hydrogen and ammonia can deliver economies of scale and reduce overall capital costs.

Most of the steam is used to drive the compressor that feeds the nitrogen and hydrogen gas mixture to the Haber-Bosch ammonia synthesis loop. Additional steam is used to drive the refrigeration compressor that is required to recycle incondensable gases from the ammonia liquefier. It is common to use steam turbines on the drives of these machines to avoid the losses of converting the steam to power. After expansion in these turbines, some lower-grade steam is available for export.

Ultrafiltration for pure water

SOE technology is well aligned to green ammonia projects. Waste heat from the Haber-Bosch synthesis loop can be used to reduce the electrical power input requirement to the SOE by around 20% compared to PEM or alkaline technologies, due to its ability to operate at high temperatures and be fed with steam.

Water purification equipment

The catalysts used in the cells within an SOE are highly sensitive to sulphate ions as well as silicates, siloxanes, and aluminium oxides. These impurities must be reduced to less than 10 parts per billion to avoid performance degradation.

The typical feed for an electrolyser is referred to as ‘Grade 2’ in the ISO 3696:1987 standard, with a maximum conductivity of 0.1 mS/m – identical to ASTM D1193-06(2018) ‘Type 2’ water. Both the ASTM and ISO standards have silica specifications, but the permitted amount differs by almost a factor of 10 between the two standards. Also, neither standard explicitly specifies total sulphur.

As a result, developers must design water treatment systems to meet electrolyser manufacturer specifications, rather than relying solely on generic industry standards.

Primary water purification unit operations

Electrolyser feed water is typically prepared using a treatment train >>

>> similar to that used for boiler feed water in thermal power plants. However, electrolysis requires even higher purity levels, particularly for sensitive technologies such as PEM and SOE.

Raw water is first passed through mechanical screens or grates to remove large debris such as plastics, vegetation, and suspended solids.

Chemical dosing is used to aggregate fine particles and dissolved metals. For example, aluminium sulphate is commonly added to promote flocculation, allowing contaminants to form larger particles that can be removed more easily. Pre-chlorination can also support this process.

A multi-media or sand bed filter is then used to remove flocculated solids along with sludge, algae, and entrained sand from the raw water. This filter must be backwashed periodically, and the resultant water should be purified prior to discharge to the drain, sea or river.

An activated carbon filter can then be used to trap the chlorine, which would corrode membranes that are used in subsequent water purification processes and would also damage the PEM electrolyser membrane.

The activated carbon filter is not regenerated in situ and must be replaced.

In hard water regions, ion exchange softening is used to remove calcium and magnesium ions. These are especially damaging to PEM electrolyser membrane electrode assembly (MEA) catalysts.

Reverse osmosis (RO) is a core technology for the final stages of freshwater purification and seawater desalination. To purify fresh water, low-pressure reverse osmosis (LPRO) can be used. It operates at around 15 bar. The power consumption of an LPRO plant is in the order of 10kWh/m³ of treated water. Between 70% and 85% of the water is recovered.

Polishing processes

After LPRO to purify the fresh water, intermediate buffer storage is generally implemented. As water is withdrawn from the storage, it may flow through an electrodeionisation (EDI) plant for polishing. Here the power requirement is similar to LPRO at 10 kWh/m³ of water. The concentrate discharge from the EDI plant can be fed to the LPRO inlet to recover water.

Modern desalination plant

Separation Process for Water Purification © 2023 sbh4 GmbH

Feed component	Mechanical screen	Multimedia granular filter	Microfiltration (MF)	Ultrafiltration (UF)	Nanofiltration (NF)	Reverse osmosis (RO)
Large debris	↘↗	↘↗	↘↗	↘↗	↘↗	↘↗
Sand, mud, algae, and slime	↘	↘↗	↘↗	↘↗	↘↗	↘↗
Bacteria, protozoa, suspended solids	↘	↘	↘↗	↘↗	↘↗	↘↗
Viruses	↘	↘	↘	↘↗	↘↗	↘↗
Dissolved organic substances	↘	↘	↘	↘	↘	↘↗
Divalent/ multivalent Ions	↘	↘	↘	↘	↘ / ↗	↘↗
Monovalent ions	↘	↘	↘	↘	↘	↘↗
Ultrapure water	↘	↘	↘	↘	↘	↘

EDI is a mature technology that has been applied to create demineralised water for supercritical steam generation, for example, in concentrated solar plants.

After the EDI process, microbial contamination can be removed. Post-chlorination is not a suitable technology, due to the incompatibility of chlorine with the sensitive electrolyser components, such as the polymer electrolyte membrane that is at the heart of the MEA in a PEM electrolyser. Therefore, a UV steriliser lamp is generally used to kill any bacteria that may be present.

Following the UV lamp, an ultrafilter traps the dead bacteria. The power requirement for the ultrafilter may be around 3kWh/m³ of water. The ultrafilter is periodically backwashed to clear the filter media cake. As with other backwash waters, this waste must be treated prior to discharge.

Dissolved gases like oxygen, nitrogen, and carbon dioxide (CO_2) must also be removed. CO_2 is unwelcome in the electrolyser because it is broken down through electrolysis to form carbon monoxide (CO). This will be an impurity in the hydrogen, making the product unsuitable for fuel cell applications.

At this stage, the ultrapure water is finally ready to be introduced to the electrolyser water or lye recirculation circuit.

Sea water for electrolysis in arid locations

Many large-scale green hydrogen projects are proposing to use renewable power generation from wind and solar resources. Integration of wind and solar can improve the firmness of renewable power generation.

Hybrid schemes of this kind will be optimal in countries such as Southern Chile, western Namibia, Morocco and the east coast of Oman. Western Australia, Northwestern Saudi Arabia, northeastern Egypt and parts of northern and western China are also blessed with ideal conditions for integrated wind and solar power generation.

In many cases, access to seawater and desalination infrastructure is becoming a primary site selection factor for large-scale green hydrogen projects.

However, in each of these locations, rainfall is neither sufficient nor steady enough to provide water for large-scale electrolysis. Seawater is the preferred source of water for electrolysis. It requires desalination, in addition to purification. Desalination is used extensively in the Middle East to make water available for the emerging vertical farming sector and coastal cities. The same knowledge can be transferred to electrolytic hydrogen production.

Seawater reverse osmosis (SWRO) is a common desalination process and has largely replaced less efficient thermal desalination. However, where waste heat from power generation can be used for desalination, thermal desalination techniques using mechanical vapour recovery to upgrade steam can be the most economic option.

During SWRO, an operating pressure of around 80 bar is used to achieve desalination. Due to the high-pressure operation, the power draw is around four times that of the LPRO system used to purify fresh water.

To generate one litre of ultrapure water, approximately three litres of seawater must be extracted and processed. The remaining two litres can be treated to remove any chemical residues and then returned to the sea.

As green hydrogen projects scale, water infrastructure will become increasingly strategic. While ultrapure water systems represent a relatively small share of project cost, they are fundamental to operational reliability, electrolyser performance, and overall project viability.

In water-constrained regions, integrated desalination and purification systems will be a defining component of successful hydrogen and ammonia developments.