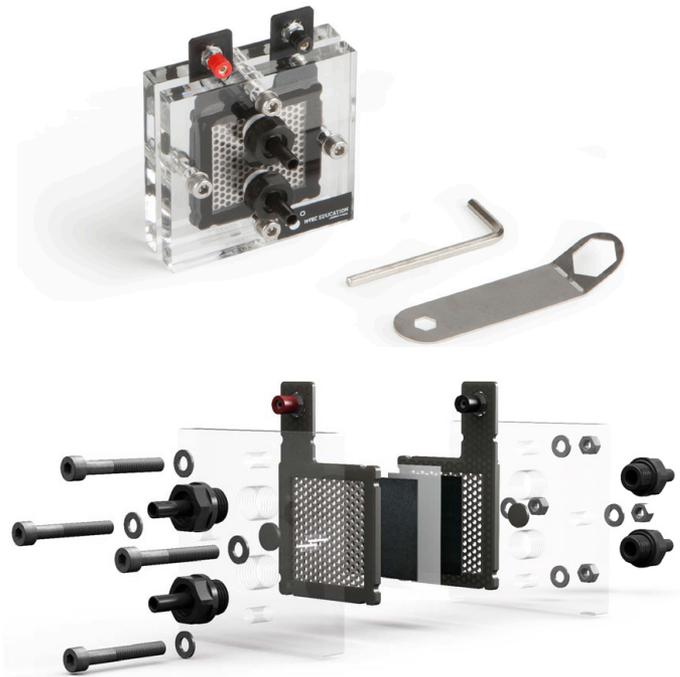


Operating Instructions



E208 - 1-Cell Rebuildable PEM Electrolyzer Kit

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Introduction

Diminishing resources, more severe environmental impacts originated from the current power plants, and the ever-increasing demand for energy forces us to re-evaluate the structure of our energy storage supply systems. Automobile and oil companies increasingly invest in hydrogen technologies (such as fuel cells, electrolyzers, etc.) because such clean technologies offer smart and innovative solutions to some of these future energy related concerns. The Proton Exchange Membrane (PEM) Electrolyzer is one of the most fascinating, clean electrochemical technologies. It provides a unique and highly efficient energy storage via an electrolysis reaction, with minimal impact on our natural resources.

It is important to learn about this technology, especially for young people, who will most likely spend a large part of their lives with it.

The 1-Cell Rebuildable PEM Electrolyzer Kit offers the possibility to become familiar with hydrogen technologies (particularly generation of hydrogen) in a step-by-step procedure, by way of simple experiments.

The 1-Cell Rebuildable PEM Electrolyzer Kit represents the state-of-the-art technology for the components that are used in the hardware. It can be used for practical demonstration of the operation of electrolyzers (which are also known as hydrogen generators in the industry) by means of simple experiments. This electrochemical cell can be completely dismantled (meaning disassembled and reassembled) and can therefore also be used for vivid demonstration of an electrolyzer design to students or researchers.

The 1-Cell Rebuildable PEM Electrolyzer Kit is consistently environmentally conscious in all operating modes, requiring only de-ionized or distilled water and a small power supply for the generation of hydrogen and oxygen gases from the electrolysis reaction of water.

All steps required for setup, operation, and assembly/disassembly of the 1-Cell Rebuildable PEM Electrolyzer Kit are described in this manual.

Please read through the Operating Instructions carefully before operation.

H-TEC Education wishes you many enjoyable hours learning about this technology with the 1-Cell Rebuildable PEM Electrolyzer Kit.

Intended Use

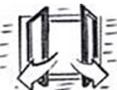
The 1-Cell Rebuildable PEM Electrolyzer Kit allows the measurement and demonstration of the principles of Proton Exchange Membrane (PEM) Electrolyzers and PEM Fuel Cells. The system has been developed for teaching and demonstration purposes only.

Any other use is prohibited!

De-ionized or distilled water, a power supply, and a multimeter are required for the operation of the 1-Cell Rebuildable PEM Electrolyzer Kit.

Should the equipment be used improperly, the generated hydrogen and oxygen gases present a hazard. Additionally, the externally attached power supply may also become a point of hazard in the case of incorrect usage of this educational PEM Electrolyzer Kit. To prevent accidents, observe the General Safety Precautions at all times when working with the 1-Cell Rebuildable PEM Electrolyzer Kit.

General Safety Precautions

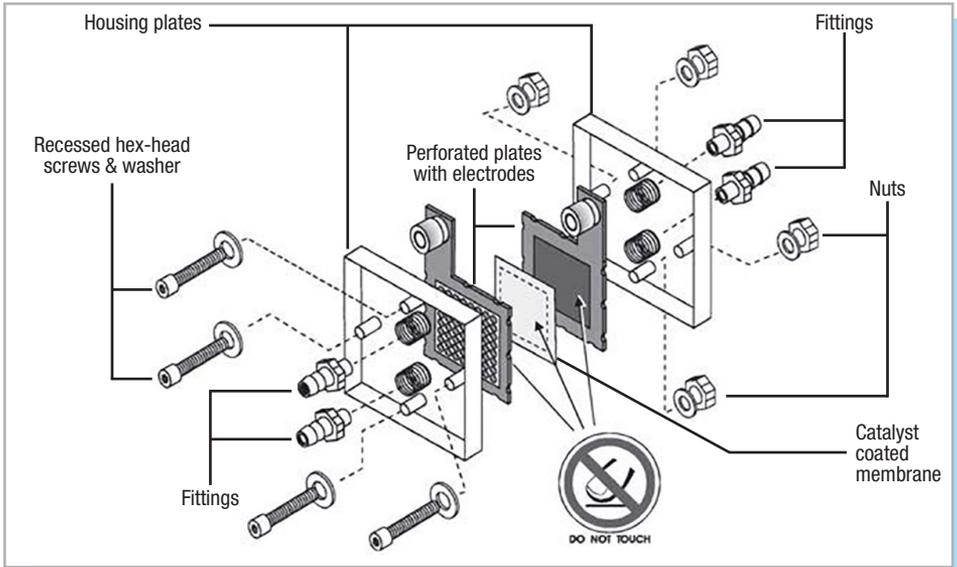
- The system is intended for teaching and demonstration purposes in schools, universities, institutions, and companies only.
- It may only be set up and operated by a competent person.
- Read the Operating Instructions before setting up the 1-Cell Rebuildable PEM Electrolyzer Kit. Follow them during use and keep them readily available for reference.
- Wear protective goggles and other PPEs.
- Remove inflammable gases, vapors, and fluids from the vicinity of electrolyzers and fuel cells. The catalysts contained in the system can trigger spontaneous combustion.
- Hydrogen and oxygen are the two main gases that are generated by the electrolyzer system. To prevent the gases collecting and forming explosive mixtures only use the system in well-ventilated rooms. Do not obstruct the inlet and outlet ports of the system and prevent pressure building up inside the cell. 
- Hoses, plugs, and tanks are used for pressure compensation. They must not be fixed or secured with clamps, adhesive, etc.
- The system is not a toy. Operate the 1-Cell Rebuildable PEM Electrolyzer Kit according to the instructions provided in this booklet and keep the cell and the gases produced by the electrochemical cell out of the reach of small children.
- Unless specified otherwise, do not short-circuit or reverse the polarity of the terminals.
- Do not operate the system dry. Always ensure that it contains sufficient liquid de-ionized water or liquid distilled water at the anode side of the electrolyzer cell.
- The system may only be operated in a display case, which is sufficiently ventilated at all times. The operator is obliged to prove this by means of appropriate measurements.
- Do not smoke near this device. 
- Only use the gas storage tanks belonging to or supplied with the system to store the generated gases during the operation of the electrolysis cell. Never connect other alternatives.
- Only operate the system at room temperature and ambient pressure.
- De-ionized water or distilled water needs to be transferred into the anode side of the electrolyzer cell in the liquid form or while its temperature is in the range of 5 deg. Celsius to 60 deg. Celsius. In the case of using warmed liquid water, the user needs to use the proper PPE.

General Safety Precautions

- Do not operate the system dry. Always ensure that it contains sufficient amount of liquid de-ionized water or liquid distilled water at the anode side of the electrolyzer cell.
- Remove anything in the vicinity of the electrolyzer cell that may ignite the generated hydrogen gas (naked flame, materials that can become charged with static electricity, substances with catalytic properties such as platinum powder, etc.). 
- Remove all the substances from the vicinity of the system that could spontaneously ignite with increased oxygen concentration.
- Tell the students about any potential dangers and carefully supervise experimentation.
- Hoses, plugs, and tanks, etc. are used for pressure compensation. They must not be fixed or secured or obstructed with clamps, adhesive, stoppers, etc.
- The power source of this electrolyzer can be based on solar sources too. Do not position any solar modules and lights in use closer than the minimum permitted distance (50 cm between H-TEC Education solar modules and the H-TEC Education Spotlight, or see other manufacturers' stipulations).
- The surface of solar modules can get very hot during extended operation.

H-TEC Education does not accept responsibility for injuries or damage sustained in the event of these Safety Precautions not being followed.

Contents



This PEM electrolyzer cell can be fully disassembled and re-assembled in order to see the design aspect and the internal components for educational purposes.

This PEM electrolyzer cell can also be used in conjunction with other educational fuel cell kits in order to consume the generated hydrogen and oxygen gases to produce electrical energy.

Required Additional Components/Equipments:

- **Commercial distilled water (or deionized water)** with a conductivity of $< 2 \mu\text{S/cm}$
- Connecting hoses
- Power supply (0 to 2.5 V and 0 to 5 Amps)
- Multimeter

Optional Equipments:

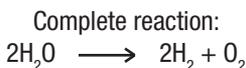
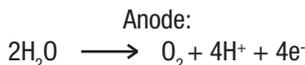
- Fuel Cell $\text{H}_2/\text{O}_2/\text{Air}$
Item No: F103
- Storage 80
Item No: A153

Operation of a PEM Electrolyzer Cell

In an electrolyzer cell, the electrical energy that is being provided from an external source is used to split the de-ionized water (or distilled water) in order to generate hydrogen and oxygen gases. In other words, electrical energy is being converted into chemical energy with the aid of the electrolyzer cell. This electrochemical reaction is also known as electrolysis.

In the electrolyzer cell, the electrochemical reactions are carried out on the catalyst located at the anode and cathode. In PEM electrolyzers, anode and cathode catalysts are usually applied directly to the surface of the membrane. Sometimes, only the anode electrode catalyst is applied to the membrane surface and cathode catalyst is applied to the surface of the gas diffusion layer. An example for anode catalyst is iridium ruthenium oxide or iridium black. An example of cathode catalyst is platinum black or platinum on carbon. As the name suggest, PEM electrolyzers utilize a proton (H^+) exchange membrane (such as Nafion). In addition to these components, a metallic diffusion medium is used at the anode side to evenly disperse the liquid water, vent out the generated gases, and provide electrical contact. At the cathode, on the other hand, a carbon based gas diffusion layer is used to vent out the hydrogen gas and also provide electrical contact.

The combination membrane-catalysts-diffusion media forms the heart of the PEM electrolyzer cell. The following reactions take place within the PEM electrolyzer system:



In this 1-Cell Rebuildable PEM Electrolyzer Kit, de-ionized water (in the liquid phase) is supplied to the anode chamber. Under the catalytic action of the anode electrode, water molecules get oxidized to oxygen gas, protons (H^+), and electrons (e^-) on the surface of the catalyst particles. The H^+ ions migrate through the proton-conductive membrane to the cathode side due to the existing cell voltage gradient. The electrons, on the other hand, travel to the cathode through the external electrical circuit and recombine with protons in order to generate the hydrogen gas. At the anode, an oxidation reaction would occur. At the cathode, on the other hand, a reduction reaction would occur. In any electrochemical cell (whether using an electrolyzer or fuel cell), an oxidation reaction has to accompany a reduction reaction in order to maintain the ion and electron neutrality.

Different Operational Modes for Electrolyzers

“Anode-fed” versus “Cathode-fed” electrolysis modes

PEM electrolyzer hardware are usually configured to work in one of the following mode: anode-fed or cathode-fed. The mode of operation is usually dictated by the application itself. For example, if the application requires pure hydrogen with minimal moisture content, the anode-fed design is more efficient. If the application requires pure oxygen with minimal moisture, the cathode-fed design is more applicable.

In the anode-fed configuration, the liquid de-ionized water is transferred to the anode chamber. On the other hand, the cathode-fed mode requires the liquid de-ionized water to be transferred to the cathode chamber.

Anode-fed configuration would usually have the following sub-components in the electrolyzer cell as its diffusion media: carbon-based gas diffusion layer for the cathode and metallic mesh or metallic screen for the anode. Cathode-fed electrolyzers, on the other hand, would have the following as its diffusion media: metallic mesh or metallic screen for anode and metallic mesh or metallic screen for the cathode.

Since electrolysis reaction requires the water to be present on the anode electrode catalyst layer, anode-fed designs are more efficient compared to cathode-fed designs. While anode-fed design allows the water to be transferred directly to the anode catalysts, the cathode-fed design would have to wait for water molecules to be transferred from cathode side to the anode through the membrane (natural diffusion, which is a slow process) before the electrolysis reaction can start.

1-Cell Rebuildable PEM Electrolyzer Kit is based on anode-fed electrolysis mode and hence, it requires the de-ionized water to be transferred to the anode chamber. De-ionized water can be transferred to the anode inlet port via two simple mechanisms: gravity-fed by using another H-TEC Education product such as Storage 80 (Item No: A153) or forcefully-fed (also known as active-fed approach) with the help of a small liquid pump. If the gravity-fed approach is being used, the user should store the water in a manner such that the water level is higher than the top port on the electrolyzer. If the user is intending to use a small liquid pump, there is no need to place the storage tank at a higher level because mechanical movement of the pump will actively push the water. The maximum amount of water to be pumped is not to exceed 70-80 milliliters per minute. Too much water flow can create leaks around the seals.

In order to prevent damage to the cell, the anode should remain full of water at all times.

Different Operational Modes for Electrolyzers

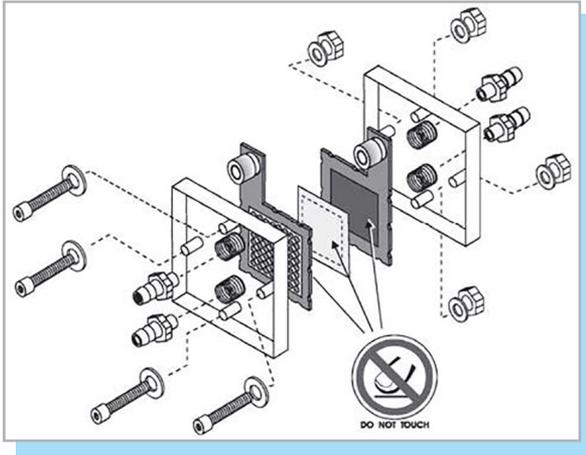
“Anode-fed” electrolysis mode

Before attaching the power supply to the electrolysis cell, it is advised to follow the following steps:

1. Obtain a pure de-ionized water (or distilled water) in sufficient quantities. 500 mL to 1000 mL of volume of water can be used for multiple hours.
2. Transfer a sufficient amount of water in to the water storage tank that you will be using for the electrolysis experiment.
3. Use a soft tubing (such as silicone tubing) of the appropriate diameter to make a connection between the water storage tank and the inlet of the anode side of the electrolyzer cell.
4. Attach another piece of soft tubing to the outlet of the anode side of the electrolyzer and place the end of this tube into the water storage tank. (During the electrolysis reaction, only a small quantity of liquid water is used and unconsumed water should be recycled back into the storage tank for further use and reduce waste).
5. Attach soft tubing to inlet and outlet ports of the cathode side (one piece of tubing for each port) where hydrogen generation will occur and place the ends of these tubes into another empty storage vessel. During the electrolysis reaction, some of the water will be carried over to the cathode side and if desired, this water can also be recycled. **CAUTION: Do not place the cathode side tubings' end to the storage that has anode side tubings. Hydrogen and oxygen mixtures can easily create a gas mixture with explosive nature and cause serious injuries.**
6. Place the anode side and cathode side storages away from each other in order to prevent formation of explosive gas mixtures. Ensure the area is well ventilated.
7. Do not restrict the liquid or gas flows through the tubings. Do not restrict the inlet and outlet ports located at the anode and cathode sides. Pressurization inside the electrolysis cell can cause leakages and possibly damaging the membrane and hence, the hardware.
8. Temperature of the de-ionized water can be in the range of 5° to 60° Celsius. Use caution with warmed or hot water and use proper personal protective equipments (PPEs, safety glasses or safety goggles, gloves, heat resistant gloves, lab coat, etc.) for the safe operation of the hardware and safety of the user.

Assembly

The 1-Cell Rebuildable PEM Electrolyzer Kit can be completely dismantled. This hardware can be fully disassembled and then reassembled for educational reasons. Note that the catalyst coated membrane (also called CCM) and the electrodes are extremely sensitive components. They can be removed from the cell and shown to students. However, we strongly advise against passing these components around the class.

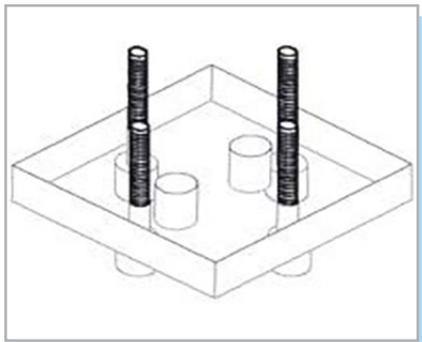


Disassembly

1. Remove the black hose fittings from the acrylic plates. Loosen the four nuts and remove the four recessed hex-head screws holding the cell together.
2. Remove the acrylic endplate.
3. Carefully remove the perforated plates from the housing plates while the membrane, cathode electrode, and anode diffusion medium are still sandwiched between the two perforated plates.
4. Then, carefully remove the top perforated plate from the rest of the components. It is possible that either the cathode electrode or anode diffusion medium may still be adhered to it (depending on which side you have started to disassemble). Then remove the membrane and the other perforated plate.

Assembly

Before refitting the membrane, allow it to soak for at least 5 minutes in deionized water.

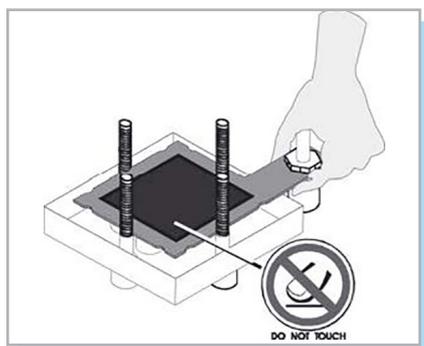


1. Place a washer over each of the four bolts. Insert the bolts into one of the housing plates and turn them so the housing plate rests upon the bolt heads (If the black fittings are removed from the housing plate, this operation can be performed on a flat bench top).

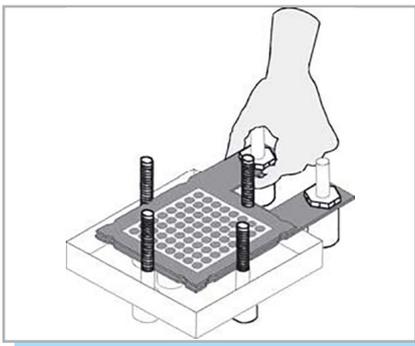
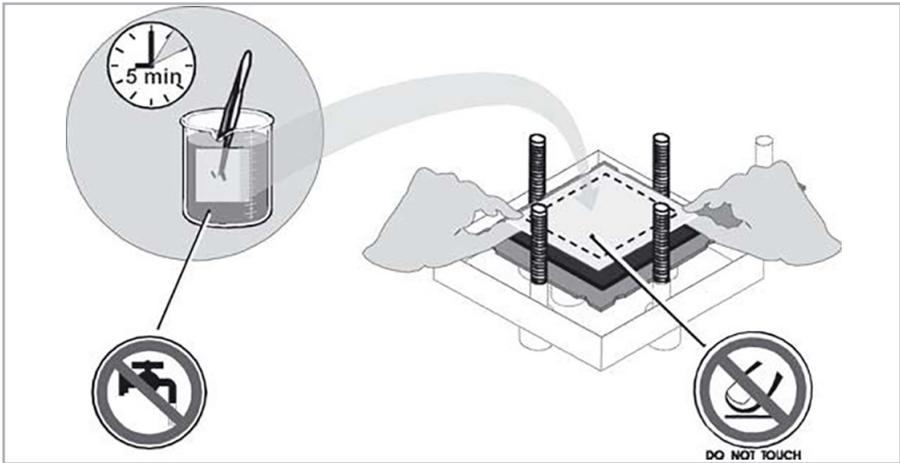
2. Place one of the perforated plates on the acrylic housing. The thicker side of the seal should face the acrylic housing plate.

3. If you have started to assemble from the anode side first, then place the anode metallic diffusion medium onto perforated plate, proceed as follows:

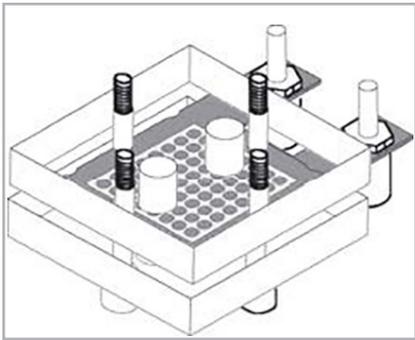
- Place the metallic diffusion medium on the perforated plate.
- Ensure the orientation of the metallic diffusion medium is correct. The perforated plates would have black colored overmold and the metallic diffusion medium needs to stay within that area that looks like a frame.
- Ensure the electrode is centered and not overlapping on the overmold area.



4. Remove the membrane from the deionized water, holding it at two opposite corners. Place it, while still wet, upon the metallic diffusion media. The anode catalyst side (matte finish) has to face towards the metallic diffusion medium and physically contact it. The membrane and metallic diffusion medium are held in position by the moisture.



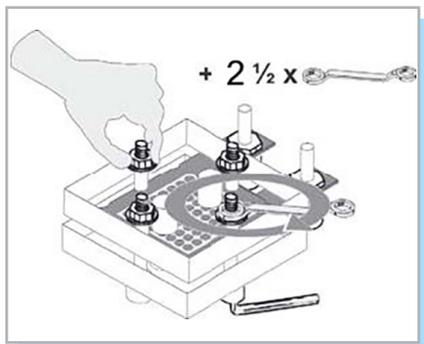
5. Place the cathode electrode (catalyzed carbon-based gas diffusion layer) onto the membrane surface. (The catalyzed side of the cathode electrode would be dark black color and the back side of the electrode would have a lighter gray color. The catalyzed side needs to face towards the membrane). The orientation of the cathode electrode should mirror the black pattern existing on the membrane. The orientation of the two electrodes must correspond. The second electrode must fit within the frame when the second perforated plate is placed in position.



6. Place the second perforated plate in position. The thicker side of the seal must face towards the acrylic housing plate which is not yet in place. The two banana jacks should be facing the same direction.

7. Place the second acrylic housing on the bolts.

8. Place the remaining washers and nuts on the bolts, and screw the nuts finger-tight at first.



9. Tighten the nuts alternately a little at a time (max. 2.5 turns) until a gap of 4mm is left between the acrylic plates.

Caution!

Overtightening may damage the electrodes. We recommend that the distance be checked by a caliper. Should a caliper or similar instrument not be available, tighten the nuts twice, approximately half a turn each time.

10. Screw the fittings into the four holes in the housing plates.

Operation of the Electrolyzer Cell

1. Obtain a small variable/adjustable DC power supply that can provide 0-5 V and 0-10 A.
2. Before connecting the power supply to the electrolyzer, set the max. voltage of the power supply to 2.1 - 2.2 Volts (voltage limited mode). Ensure that the knob for electrical current is set to 0 A before the electrolysis test. During the testing of the electrolyzer cell, it is suggested that the user vary the current while limiting the voltage.
3. Ensure that the polarity of the connections from the power supply to the electrolyzer electrodes is done correctly. The positive lead of the power supply needs to be connected to the anode side electrode which has a red colored 2mm banana plug. The negative lead of the power supply needs to be connected to the cathode side electrode which has a black colored 2 mm banana plug.
4. After making the electrical connections, turn on the DC power supply. Slowly adjust the electrical current value by turning the current knob of the power supply. Most power supplies will provide readout values both for the voltage and current parameters. A multimeter can be used to verify the voltage value at the terminals of the electrolyzer cell.
5. The maximum electrical current input value for the 1-Cell Rebuildable PEM Electrolyzer Kit is approximately 5 Amps (if warmed water at a temperature of 36-39°C is used) and the user can adjust the knob for the electrical current until 5 A is reached. If the cell voltage reaches to 2 V before 5 A is achieved, stop and do not increase the current anymore.
6. With the use of room temperature de-ionized water or distilled water, 0-4 A can be achieved before the cell voltage reaches 2 V. With warmed water that has a temperature range of 36-39°C, 0-5 A can be achieved before the cell voltage reaches to 2 V.

Technical Data

H x W x D:.....	100 x 80 x 90 mm
Weight:.....	0.2 kg
H ₂ Output:.....	35 mL/min
O ₂ Output:.....	17.5 mL/min
Input Voltage Range:.....	0 - 2 V
Input Current Range:.....	0 - 5 A*
Electrode Area:.....	16 cm ²
Guide value for Distilled Water:.....	<2 µS/cm
Permitted operating pressure:.....	0 - 20 mbar

*: The amount of electrical current that can be applied to the electrolyzer cell will depend on the temperature of the pure water. With room temperature, it is possible to achieve 0 A to 4 A. With slightly warmed water (about 40° C), it is possible to achieve 0-5 Amps. **CAUTION: The maximum voltage that can be applied to this cell is 2.1 V.**

Troubleshooting

The most frequent causes of faults during operation of electrolyzer are:

Use of contaminated water

This electrolyzer cell has a special membrane and it requires pure de-ionized water or distilled water for its operation. Use of any other water sources (tap water, lake water, sea water, etc.) will compromise the functionality of the membrane and lower its ionic conductivity. A contaminated membrane will have significantly lower performance compared to a non-contaminated membrane.

Reversed polarity connection

If the power supply connection to the electrolyzer is done wrongly and operated, the cathode catalyst and cathode gas diffusion layer will be permanently damaged.

Reversed membrane after disassembly

If the catalyzed membrane is not placed correctly after the disassembly of the hardware (such as anode catalyst side placed toward the cathode's perforated electrode), the cell will not operate or internal components may get damaged.

Insufficient liquid de-ionized water or running the cell dry

If the anode chamber does not get sufficient liquid de-ionized water or distilled water or if it operates in dry mode, components of the cell will get damaged.

Disposal

Do not dispose of electrolyzer cells or components as general household waste.

According to European regulations, used electric and electronic devices may no longer be disposed of as unsorted household waste. The symbol of the crossed-out wheelie bin indicates the requirement for separate disposal.

Your local waste management company can provide you with additional information about disposal options.



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