AREVA H_2Gen

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Assessment of water supply options and impact of using seawater on the design of electrolysers to be sited on Eday

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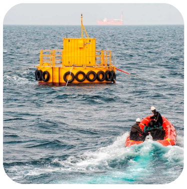


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EXECUTIVE SUMMARY

Addition of a sea water reverse osmosis unit would allow the Eday hydrogen system to be replicated in areas with water scarcity. The factors which affect reverse osmosis systems are outlined in this report, including: water quality, electrolyser and reverse osmosis consumption/production, regulations, site conditions and commercial equipment quotes.

The study has identified a number of technical aspects which make the use of seawater within the project difficult. It is believed these could be solved if additional capital, resources and time were available. In addition, the topography of the site on Eday leads to additional expense. It concludes that the purchase, installation and commissioning of a sea water reverse osmosis system could cost in excess of £500,000 to build at the site. Other options for using seawater are deemed even more expensive.

The water supply currently available on Eday, or that provided from a newly drilled local borehole providing water to the existing local potable supply specification, has also been assessed by AREVA H2Gen, the electrolyser supplying partner, and found to provide a much more viable supply solution.

The study, conducted jointly by EMEC and AREVA H2Gen, has concluded to move forward with this supply for the electrolyser system.

1 Introduction

Through the Surf 'N' Turf and BIGHIT projects, EMEC has obtained an electrolyser to harness renewable energy to produce hydrogen which can be used locally for electricity, heating and transport. Now, through the ITEG project, EMEC and AREVA H2Gen are considering the possibility of using sea water to feed a further system which will be deployed within the ITEG project on Eday. A sea water reverse osmosis (SWRO) unit would allow this system, using the electrolyser to harness a large renewable source in an area with a constrained grid, to further support the replication of the ITEG project in similar remote areas where clean water to feed such systems is not available.

This report examines how best to provide water to the electrolyser to be based on Eday within the ITEG project. It examines water quality, adaptation of the electrolyser system, commercial SWRO systems, water consumption and impact on hydrogen production of the electrolyser. It also indicates what regulations would apply if seawater extraction were to take place.

Finally, the report includes local water analysis and quotes for services, equipment and systems from various manufacturers.

2 Water quality

There are numerous measures of water quality. One that is particularly important for reverse osmosis systems is Total Dissolved Solids (TDS). This covers the content of inorganic salts and small amounts of organic matter. It is usually measure in parts per million (ppm) of mg/l. (1 ppm is equivalent to 1 mg/l.)

Seawater typically has a TDS of 35,000 mg/l. The borehole water on Eday has a TDS of 500 – 600 mg/l. This means it is "very hard".

The quality of water can have a significant effect on the maintenance needs of an electrolyser, its lifetime and the energy it needs to perform its key process of water splitting. Electrolyser suppliers, therefore, tend to request their customers to be in a position to guarantee potable water, or drinking water, quality supply to the electrolyser.

An example of a recent quotation provided by Areva H2Gen stated the following in terms of the required water quality:

"The water shall comply with drinking water directive (council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption), or meet the WHO (World Health Organization) international standards at least"

Conductivity < 2000 µS/cm at 25°C, pH between 4 and 10, pressure between 2 and 6 bar, temperature between +5 and +40°C"

This specification is given because AREVA H2Gen provides its own reverse osmosis system within the electrolyser to produce pure water from tap/potable water. Other suppliers do take the view that the reverse osmosis system can be provided by the perspective customer and as such give requirements both before and after the system.

Table 1: Hydrogenics water specification requirements for a PEM system

FEED WATER AND PROCESS WATER REQUIREMENTS		
FEED WATER REQUIREMENTS (BEFORE WATER TREATMENT SYSTEM)		
Operating Pressure	bar (psi)	2.75 – 5.50 (40 – 80 psi)
pH	Range	3 – 11
Maximum Temperature	°C	38 °C
Maximum Turbidity	NTU	1.0 NTU
Maximum Silt Density	Index	5.0 (based on 15 min. test time)
Chlorine	ppm	< 0.1 ppm
Maximum TDS	ppm	2000 ppm
Hardness	grains (ppm)	10 grains (170 ppm as CaCO3)
Iron	ppm	< 0.1 ppm
Manganese	ppm	< 0.1 ppm
Hydrogen Sulfide	ppm	0 ppm
Langelier Saturation	Index	LSI must be negative
PROCESS WATER (AFTER WATER TREATMENT SYSTEM, TO THE HYLYZER)		
Inlet Water consumption	L/h	~1 L of deionized water per Nm3 of H2 produced.
Required inlet water quality	MΩ.cm	> 1 (ISO 3696 scale 2)
Required inlet water pressure	barg (psig)	0.7 – 6.9 (10 – 100)

Generally, the water leaving the commercial reverse osmosis system is in accordance with the maximum conductivity value allowed at electrolysis process inlet. Futhermore, most of the electrolyser suppliers monitor the conductivity value using a conductivity transmitter placed inside the water loops within the electrolysis process.
In the case of a PEM electrolyser, the process is fed with pure deionised water. The deionised water reacts with parts of the system made from stainless steel (piping, components, vessels, …) and ions are released that makes it necessary to add an additionnal "polishing treatement" to remove them.

Sampling and testing of the various water streams/sources to confirm the above is recommended before any purchase. Inlet water quality analysis is very important in order to define the final specification of the reverse osmosis unit. Depending on the impurities contained within the tap/potable water, occasionally an additional cartridge is required to protect the reverse osmosis unit from impurities which might cause it to fail and to be sure that outlet water quality will comply with electrolysis process water quality specification

Water specifications are a key issue in the operating costs of the electrolyser and can lead to disputes between the supplier and customer. It should also be noted that water quality, especially from a naturally occurring water supply.

It is recognised by all electrolyser suppliers that working towards an eased specification in terms of water quality will help to ensure a wider geographical application of the technology and improved operations.

3 Standard electrolyser and reverse osmosis production/consumption

3.1 Reverse osmosis purification unit

Efficiency of reverse osmosis water purification unit is given by the ratio between pure water produced (outlet) and potable/tap water consumed (inlet).

Le figure below show the efficiency of Reverse Osmosis unit from the Merck-Millipore company which is a leader in the field of water treatment for laboratory and small scale pure water production.

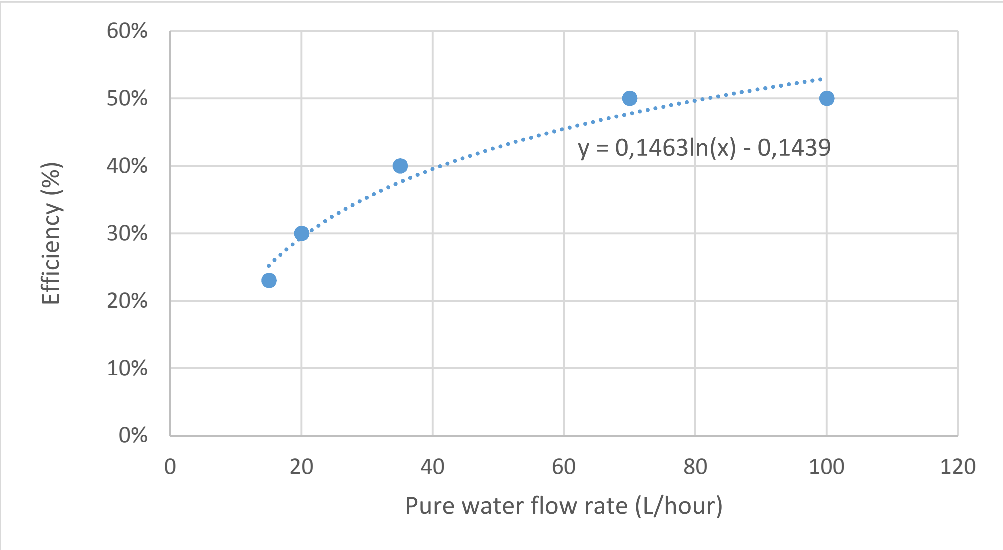

Figure 1: Merk-Millipore reverse osmosis unit efficiency

The lower the pure water production, the lower the efficiency is. For pure water production lower than 70 L/hour, efficiency is between 23% and 50%. Higher than 70 L/hours, the efficiency remains constant at 50%.

Using these data, we are able to calculate the potable/tap water required depending on pure water consumption of the electrolyzer (see figure below).

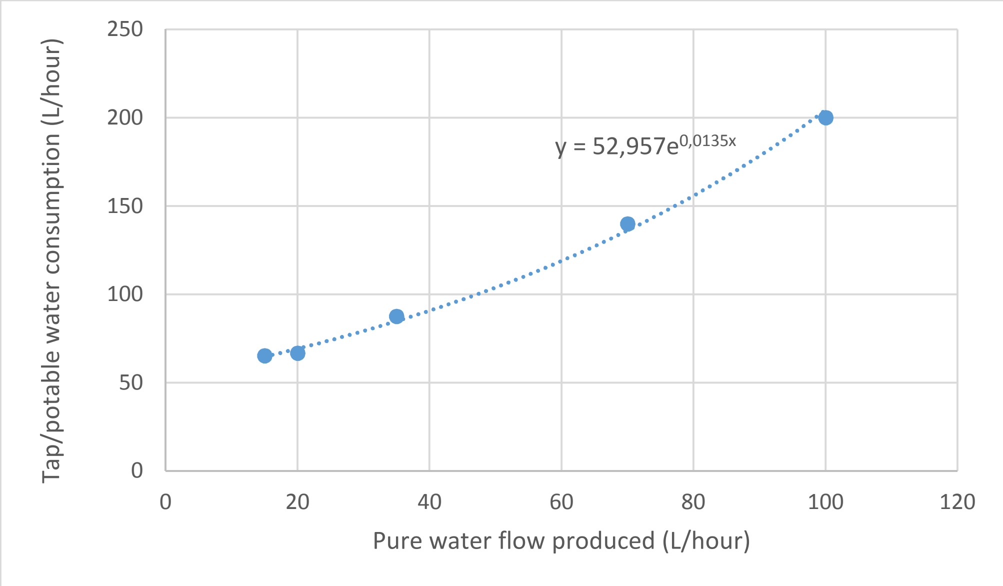

Figure 2: Tap/potable water depending on pure water flow rate requirement (Mark-Millipore reverse osmosis unit)

3.2 Electrolyser water consumption

Generally, in order to determine the tap/potable water consumption of the electrolyser, suppliers take the assumption that 1 L of pure water is consumed per Nm3 of hydrogen produced.

So, in order to produce 1 kg of hydrogen (11 Nm3/kg), the electrolyser requires 11 l of purified water.

For example, an electrolyser designed to produce 35 Nm^3/h of hydrogen (equipped with a 35 L/hour reverse osmosis unit), the deionising unit requires 27.5 L of water from the bore hole to produce 1 kg of hydrogen. 11 L of pure water is fed to the electrolyser process and the remaining 16.5 L is sent to the water drain. This is shown in Figure 3.

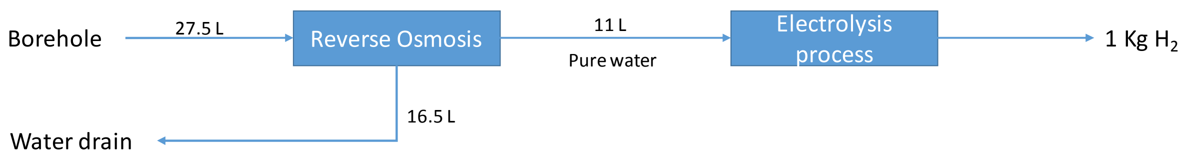

Figure 3: Block flow diagram of water consumption and hydrogen production

In the case of ITEG project, nominal power of the electrolyser is about 500 kW up to 1 MW at maximum power equipped with a 50% efficiency reverse osmosis unit.

So, at nominal load the electrolyser should produce 218 kg H_2 per day considering continuous operation of the process (24 h/day). Thus required 4 800 L of tap/potable water to be sent to the reverse osmosis process per day in order to produce 2 400 L of pure water for the electrolysis process

At maximum power load (1 MW), the electrolyser should produce 18 kg H_2 per hour. If we are considering continuous operation of the process (24 h/day), electrolyser should produce 436 Kg H_2/day. Thus required 9 600 L of tap/potable water to be sent to the reverse osmosis process per day in order to produce 4 800 L of pure water for the electrolysis process

However, the water consumption of the electrolyser will be relatively small compared to the usage for farming operations on Eday.

In addition, the water which is rejected from the deioniser is effectively just enriched with certain ions. This water could still have multiple purposes despite having been used for this purpose such as most industrial ‘grey water’ applications, irrigation of some kind of crops and processes as simple as flushing toilets. Areva H2Gen carried out an analysis of the rejected water recently which is attached in Annex 3.

4 Seawater electrolyser design considerations

4.1 Seawater electrolyser

Within the ITEG project Areva H2Gen have considered the development of a new electrolyser system capable of introducing seawater as a water feed for the overall system.

The initial consideration was whether the electrodes could operate with a full seawater feed. A desktop study of available data was made, and, through the activities within the Atlantic Area Interreg project, SEAFUEL, which Areva H2Gen's UK partner HyEnergy Consultancy is a partner of, the findings of the study were indicatively confirmed by experiments performed as part of the SEAFUEL project by University of Liverpool.

Areva H2Gen concluded that this was not a commercial route that could be followed at the current time. It is probable that these systems would operate at a low power density and electrolyze only a small portion of the water in contact with electrodes.

Despite the communication made by Stanford researchers on March 2019[1] significant further research time and funding would be required before the company would consider including technology to enable such feedstock to be considered.

New technologies must be developed to solve the probable corrosion and contamination problems and undesirable electrochemical products such as chlorine and electrical leakage current due to the presence of ions within the water.

4.2 Electrolyser integrating seawater treatment process

A further alternative was then considered – the inclusion of a bespoke seawater clean-up system designed internally. The design engineering team considered how best the system could be integrated within the electrolyser to optimise waste streams. In parallel, the team looked at commercially available clean-up systems to assess whether these provide a suitable alternative.

The conclusion of these studies has been that any attempt to integrate the system would require significant resources and, given the funding available within this project, this is not a viable route forward. The work identified that there could potentially be some energy integration opportunities by combining the systems.

4.3 Seawater treatment unit feeding electrolyser

Finally, standard seawater purification systems have been considered. These are reasonably available within the market from a number of different suppliers. It was concluded that,

[1] https://news.stanford.edu/2019/03/18/new-way-generate-hydrogen-fuel-seawater/

should Eday's water source is not of sufficient quality to enable electrolysis, this route would be the preferred to enable the hydrogen production to occur.

Seawater desalination systems are generally used to produce drinking water. The production of drinking water is carried out in 2 main process as shown in the figure below:

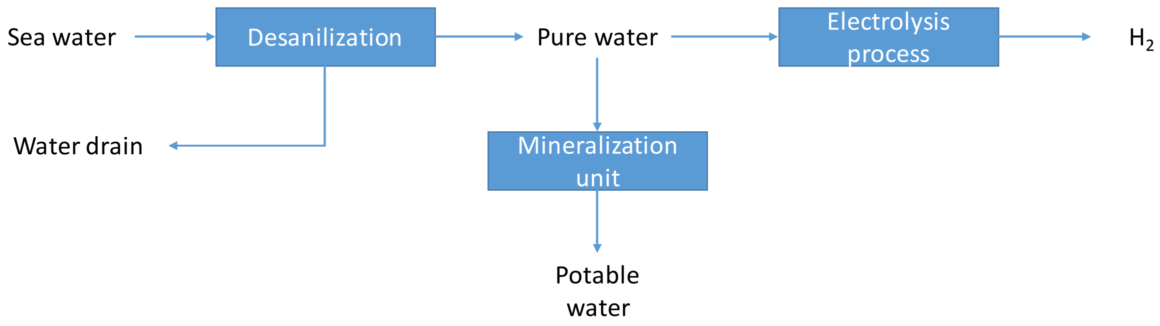

Figure 4: Block flow diagram of seawater treatment for drinking water production and H2 production

1- Removal of all organic, inorganic, ions impurities leading to a very pure and deionized water
2- Remineralization of this pure water to make it fit for consumption.

If we are considering seawater clean-up unit to feed a water electrolyser, the quality of the water produced at the outlet of step 1 is sufficient to be feed the electrolysis process. Step 2 would then be useless. It would then be possible to supply the electrolysis process directly and to eliminate the reverse osmosis unit conventionally installed in the electrolyser.

Quotes were asked for a 250 L/h machine. However, late in the process of retrieving quotes one of the suppliers pointed out that a 250 l/h machine would not produce constantly for the 24 hours, so it would fall short of the goal of 4800 L/d goal. This should be born in mind going forward.

There is potential for installing a buffer tank to store water between the SWRO unit and the electrolyser. Ultimately the system will depend on how the electrolyser will be operated, which is a question that is still to be answer.

In any case this is a relatively small unit as SWRO machines go.

There is an energy penalty for running the SWRO machine, but it is not very great – less than 1 kWh/kg H_2.

5 Regulations/planning permission

Extraction of seawater falls under the Water Environment (Controlled Activities) (Scotland) Regulations 2011 (CAR). We would have an abstraction and a discharge. The abstraction is less than 10 m3 a day, so falls under General Binding Rules Category. The discharge will need a registration, which is a one-off fee of £133.

6 Eday site conditions

6.1 Seawater supply

Figure 5: General view of Eday topography

Figure 6: EMEC site and sea access

In order to make use of the huge volume of sea water a feed-pipe would have to be run from the sea to the SWRO.

To ensure a reliable seawater supply, because the beach is very gradually sloping, it is likely to require up to 2km of piping out to sea. This would require a geological survey, several months of marine operations with large vessels, an amphibious digger for several days and the likely build of a new road to Cauldale to gain the necessary access for the required equipment.

Another possible option is to install a sea wall, create a lagoon or dig out the beach to artificially create enough depth to ensure constant supply of water. A rough estimate of these works, from previous experience, is c. £1million.

Operationally, any seawater supply solution will require constant maintenance to ensure mussels do not block the feed pipe. It is expected that the cost of the divers required to conduct this exercise will cost c. £40,000 cost per year.

Assuming this cost could be overcome the data gathered by Slesser and Turerell (2013) on the composition of seawater and how it changes over the year was used to provide an example of what could be expected in Eday coastal waters.

6.2 Borehole supply

An alternative method of providing water to the EMEC site in suitable quantities is the drilling of a borehole. EMEC sourced a quotation for this option and it is given in Annex 1. The location of the borehole to the EMEC site is given in Annex 2.

Given that most of the water used on Eday currently comes from borehole supply this route is considered very feasible if any existing supply sources are not deemed to be able to provide a sufficient flow rater for the electrolyser.

6.3 Supply assessment

Given the cost impact to the project and the installation overall, and the fact that it is expected that the borehole solution will provide water of adequate quality and flowrate, this solution is preferred.

6.4 Electrolyser impact

TDS of Eday seawater was found to be particularly high while the average concentration is 35g/l. Such a value will have a significant impact on the high-pressure pump (cost and dimension, electricity consumption) and on the number of reverse osmosis modules.

It has been assumed by Areva H2Gen that the water supply will be at least as good as the analysis contained in Annex 4 of the general potable water supply on Eday – whether from the borehole or an existing supply arrangement.

Assuming this will be the case then the system will be designed to meet these criteria.

7 Conclusions

The study has identified a number of technical aspects which make the use of seawater within the project difficult. It is believed these could be solved if additional capital, resources and time were available. In addition, the topography of the site on Eday leads to additional expense. It concludes that the purchase, installation and commissioning of a sea water reverse osmosis system could cost in excess of £500,000 to build at the site. Other options for using seawater are deemed even more expensive.

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ANNEX

LIST OF ANNEX