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Benefits of external heat sources for high temperature electrolyser systems

Floriane Petipas [a,b], Annabelle Brisse [a,*], Chakib Bouallou [b]

[a] European Institute For Energy Research (EIFER), Emmy-Noether-Str 11, 76131 Karlsruhe, Germany
[b] MINES ParisTech, Centre for Energy Efficiency of Systems (CES), 60 bd Saint Michel, 75006 Paris, France

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ABSTRACT

High Temperature ELectrolysers (HTEL) operate around 1073 K with steam at 1073 K. Water is previously heated up in the Balance of Plant by the hot outlet gases and optionally by electrical heaters. If liquid water is fed to the system, vaporisation needs are covered by electrical heating, which leads to a low system efficiency of 89% vs. HHV. Using steam instead of liquid water would suppress vaporisation needs, thus increase the efficiency. This work aims to analyse the potential benefits of a steam supply. Calculation is performed without considering the energy required to preheat water. Results show that feeding the system with low-temperature steam instead of liquid water enables a system efficiency jump of 18%. Further increasing the steam temperature to 933 K negligibly impacts the system efficiency and is therefore unnecessary. It is concluded that a low-temperature steam source is sufficient to increase significantly the HTEL system efficiency.

1. Introduction

1.1. Power to gas

In 2009, the global electricity production was 20 PWh (1 PWh = 10^{15} Wh) and was 67% based on fossil fuels (41% coal, 21% natural gas, 5% oil) [1]. The European objectives of increasing the share of renewable energy sources, such as wind and solar, imply the development of electricity storage solutions.

Electricity is presently mostly stored through pumped-storage hydroelectricity, whose capacity is however limited and geographic dependent. Hence, there is a strong need for technologies that can store large amounts of electricity for long periods of time. Various electricity storage solutions are developed in order to tackle this challenge. Two main storage types exist depending on the storage capacity and the discharge time. Indeed, technologies with small storage capacities (<1 MWh) and short discharge times (<1 h), such as flywheels and batteries, are better suited to manage small power variations over short periods of time. On the contrary, technologies with large storage capacities (>1 GWh) and large discharge times (>1 day), such as Compressed Air Energy Storage (CAES), pumped-storage hydroelectricity, as well as the production of hydrogen and methane, are better suited for large seasonal storage.

The conversion of electricity into another energy carrier, which can be stored and used directly as a fuel, is an attractive option. In this framework, the Power-to-Gas concept [2,3]

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[*] *Corresponding author*. Tel.: +49 721 6105 1317; fax: +49 721 6105 1332.
E-mail address: brisse@eifer.org (A. Brisse).

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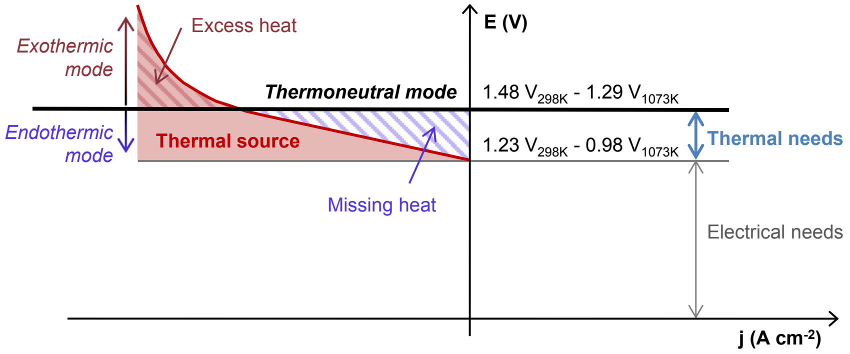

Fig. 1 – **Polarisation curve of an electrolysis cell.**

consists in converting electricity into hydrogen (H_2), which can be further converted into methane (CH_4). Hydrogen is presently mostly dedicated to the industry sector for oil refining and for ammonia production. The global hydrogen production is about 55 million tons per year and is almost entirely based on fossil fuels (49% natural gas, 29% oil, 18% coal) [4]. Renewable hydrogen can be hence produced as a renewable electricity storage solution by the electric power industry, and used as a carbon-free fuel by the oil and gas industry.

The conversion of electrical energy into hydrogen is done electrochemically within an electrolyser. The water electrolysis reaction can be performed below 373 K with liquid water using an Alkaline ELectrolyser (AEL) or a Proton Exchange Membrane ELectrolyser (PEMEL), or above 773 K with steam using a High Temperature ELectrolyser (HTEL, based on Solid Oxide Electrolysis Cells, SOECs). Performing the reaction within an HTEL is particularly interesting because of the higher system efficiency, even when no external heat source is provided [5,6].

1.2. *Thermal contributions in HTEL systems*

The higher system efficiency is related to the thermal management. HTEL systems are mostly composed of electrolysis cell assemblies (or SOEC stacks) and a Balance of Plant (BoP). This section aims to explain the different thermal contributions occurring within the SOEC stacks and within the BoP.

Indeed, several thermal contributions occur within the SOEC stacks, which operate at 1073 K with steam at 1073 K:

→ SOEC thermal needs related to the endothermic water-electrolysis reaction
← SOEC thermal source related to the overvoltages mostly provoked by the ohmic resistance

As illustrated in Fig. 1, the thermoneutral mode is reached at the nominal (or thermoneutral) cell voltage, for which the thermal needs equal the Joule heating related to the overvoltages. In the endothermic mode, the cell voltage is lower than the nominal voltage, hence the thermal needs are partly covered by the Joule heating. The thermal needs are complementarily covered by thermal energy from the environment, in particular from the reaction gases, which in turns leads to a temperature decrease. In the exothermic mode, the voltage is higher than the nominal voltage, hence thermal needs are entirely covered by the Joule heating which is in excess. The excess heat is dissipated as thermal energy to the environment, in particular to the reaction gases, which in turns leads to a temperature increase.

At the nominal voltage (thermoneutral voltage), the heat dissipated by the Joule effect balances the reaction needs. Since the dissipated heat is entirely valorised, the cell efficiency is very high. This aspect is crucial because it corresponds to the main advantage of high temperature electrolysis over low temperature electrolysis (operated with liquid water below 373 K), which is always performed in the exothermic mode at much higher voltages than the thermoneutral voltage, thus at much lower cell efficiencies.

The Balance of Plant (BoP) is composed of auxiliary components which ensure that the SOEC stacks operate under optimised conditions. These components provide the SOEC stacks with steam at 1073 K and cool down the outlet gases to 298 K. Several thermal contributions occur outside the electrolysis cells, within the BoP:

→ BoP thermal needs related to the inlet gases heat-up
← BoP thermal source related to the outlet gases cool-down
← Optional: BoP thermal source related to hydrogen compression
← Optional: BoP thermal source related to hydrogen storage in hydrides
← Optional: External thermal source, such as waste heat

At the nominal voltage (thermoneutral voltage), the outlet gases temperature equals the inlet gases temperature of the SOEC stacks. When no external heat source is provided, electrical heating is necessary as a complement to heat recovery to fully heat up the inlet gases to the operating temperature. The system efficiency is calculated by taking into account the power consumption of the BoP. The HTEL system efficiency is around 90% vs. HHV [5,6], which is higher than the system efficiency of low temperature electrolysers (60–75% vs. HHV). This difference is due to the much higher cell efficiency at higher temperatures, as explained above, combined with the fact that the dissipated heat cannot be valorised in the BoP at low temperature. When using additionally an