Engineering, Construction, and Commissioning of a 4 kW Aluminium-to-Energy CHP-Unit

Prototype of the Horizon Europe Project REVEAL WP4

Graduate

Jan Hüppi

Introduction: Today, electricity and heat can be generated from renewable energy sources at relatively low cost, and there are a number of cost-effective short-term storage solutions. However, technologies for the long-term storage of renewable energy remain scarce and expensive. A promising option for seasonal energy storage that is currently being researched is the aluminium-based energy storage cycle (cf. Fig. 1). The charging of the storage is achieved by the reduction of oxidised aluminium (Al^{3+}) to elemental aluminium (Al) in central processing plants at locations and times of high availability of renewable electricity. In places and at times with high energy demand and low availability of renewable energy, discharging takes place through aluminium oxidation. A significant drawback of this concept is that both the technologies for charging (Power-to-Al) and discharging (Al-to-Energy) the storage are not yet well developed.

Objective: The main goal of this thesis is to develop and construct a continuously operating Al-to-Energy CHP-unit with a total output of 4 kW (3 kW thermal & 1 kW electrical), which can then be tested as a part of the EU-Horizon Project REVEAL. The most important boundary conditions are that the aluminium-water oxidation reaction must take place at a temperature below 100 °C and in a sodium hydroxide (NaOH) solution.

Result: As part of this work, a process engineering concept for a continuously operating Al-to-Energy CHP-unit was successfully developed, and a prototype with a total power output of 4 kW was designed and built. The three main components of the prototype built are the Reaction Vessel, the Crystallisation Vessel and the Sedimentation Vessel, all of which are filled with a specific amount of 2 M NaOH solution and are under a defined overpressure (1.5-3.9 bara). In the Reaction Vessel, the Al-water oxidation reaction takes place at a temperature of 70 °C and hydrogen and aluminium hydroxide ($Al(OH)_3$) are formed. The reaction heat (2 kW) is extracted from the stirred solution by an internal heat exchanger and the reactants, aluminium and water, are periodically added to the vessel. To prevent accumulation of $Al(OH)_3$ in the Reaction Vessel, liquid with dissolved and solid $Al(OH)_3$ is periodically transferred to the Crystallisation Vessel where any carried over Al granules can react to completion and the crystallisation rate is kept high by stirring. At the same time intervals, liquid is transferred from the Crystallisation Vessel to the Sedimentation Vessel, where the solid $Al(OH)_3$ crystals settle to the bottom. The sediment is discharged via a valve at the bottom of the Sedimentation Vessel and the NaOH solution is pumped back into the Reaction Vessel to close the cycle. The hydrogen produced is fed to a water-cooled Fuel Cell System, where it is converted into electrical (1 kW) and thermal (1 kW) power. To compensate for short-term fluctuations in hydrogen production, a Hydrogen Buffer Tank is used. The prototype is controlled via a real-time controller and the measurement and control equipment required to operate and characterise the prototype is installed. Initial functional tests have been successfully completed, and preparations for full commissioning have been initiated.

Fig. 1: Visualisation of the aluminium based energy storage cycle. Material and energy flows exemplary for 1 kg of Al.
Own presentment

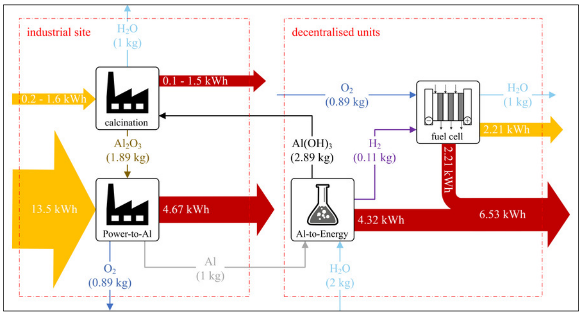

Fig. 2: Right side of the prototype. Centre: Feeder & Reaction Vessel. Right: Hydrogen Buffer Tank & heat distribution
Own presentment

Fig. 3: Left side of the prototype. Centre: Crystallisation Vessel. Right: Sedimentation Vessel. Left: Control cabinet
Own presentment

Advisor
Dr. Michel Haller

Co-Examiner
Dr. Jerman Ivan, National Institute of Chemistry, Ljubljana, Slovenia

Subject Area
Energy and Environment