Advanced aqueous alkaline batteries based on hydrogen

Dag Noréus
Department of Materials and Environmental Chemistry, Stockholm University

Aqueous batteries, based on water which is environmentally benign are promising for safe, cost-effective energy storage. Aqueous electrolytes with fast diffusion rates promoted by the Grotthuss mechanism enable high power density and tolerance against mishandling. This also simplifies the construction as thicker electrodes can be used reducing manufacturing costs. The promising combination of safety, low cost of raw materials and manufacturing, and environmental benignity should allow aqueous batteries to become good candidates for energy storage solutions. To date, considerable progress on aqueous batteries has been achieved. We have witnessed an explosive growth of publications regarding advanced aqueous batteries.

Grid-scale applications have, however, been impeded by two issues, limited energy density and unsatisfactory cycle-life.

Fundamentally, water has an inherent thermodynamic oxidation potential [oxygen evolution reaction (OER)] and a reduction potential [hydrogen evolution reaction (HER)], which differ by a narrow voltage window of 1.23 V. This narrow electrochemical stability window puts a limit to the operating voltage, leading to a low energy density of water-based battery chemistries.

Hydrogen, as charge carrier, is found in a number of rechargeable aqueous battery chemistries.

In the nickel-hydrogen battery (NiH_2), hydrogen gas is directly the active materiel.[1] A NiH_2 battery combines a reasonable specific energy of 55–60 Wh/kg with a very long cycle life (40,000 cycles at 40% Depth Of Discharge) and operating life (>15 years).[2] The cells can tolerate overcharging and accidental polarity reversal. The NiH_2-battery is thus a good choice for long lasting space missions. Especially in low orbit missions where the number of cycles soon becomes very significant. NiH_2 batteries have orbited the earth as well as Mercury (Messenger) and Mars (Odyssey and Global Survivor). When the NiH2 batteries in the Hubble Space Telescope were replaced after 19 years, they had reached the highest number of charge/discharge cycle ever.[3] As the hydrogen is stored in pressurized gas tanks, the volumetric energy density is low, which limits their practical use, even if the cycle-life is very good.

In the Hydride battery (NiMH) hydrogen is stored in the solid state as a metal hydride (MH), that also is the main part of the MH-electrode. The volumetric storage capacity in the alloy corresponds to about twice of that in liquified hydrogen, leading to a high volumetric energy storage density, at par with Li-batteries, even if the gravimetric energy density is lower. In aqueous chemistries gas reactions including oxygen and hydrogen can further be used to increase cycle-life. This makes it possible to increase the total energy throughput, (= capacity times cycle-life), to be better than in Li-chemistries.[3] When hydrogen corrodes, it forms water, when lithium corrodes it forms insolvable oxides.

Somewhat more complex chemistries are found in NiFe-, NiZn- and NiCd-batteries where hydrogen is produced by the corrosion of Fe, Zn and Cd by the electrolyte during discharge and intercalated in the Ni-electrode where Ni(III)OOH is transformed to $Ni(II)(OH)_2$. MnO_2, MnOOH and Mn^{2+} ions are also interesting in corresponding cathodes to increase electrode capacity by allowing for more electrons to be transferred. Chemistries based on hydrogen thus offers new paths for development.

References

1) Davíd Linden, Thomas Reddy (Eds.), Handbook of batteries (3rd ed.), 0-07-135978-8, McGraw-Hill (2002) [Chapter 32], "Nickel Hydrogen Batteries”

2) National Aeronautics and Space Administration. Hubble space telescope servicing mission 4 batteries. FS-2007-09-091-GSFC (SM4 #08) (rev. 11/07)

3) Y. Shen, D. Noréus and S. Starborg. “Increasing NiMH battery cycle life with oxygen” Int. J. Hydrog. Energy 2018, 43, 18626–18631

Dag Noréus is a professor in the Department of Materials and Environmental Chemistry at Stockholm University. He earned his PhD degree in reactor physics in 1982 at the Royal Institute of Technology, Stockholm, Sweden, and completed his postdoc at Daimler-Benz, Metal Hydride Laboratory, Stuttgart, Germany, in 1983. Noréus became a researcher in 1984 and a professor in 2000 in the Department of Structural Chemistry, Stockholm University. His research interests include x-ray diffraction, elastic and inelastic neutron scattering, and electrochemistry focusing on the understanding of metal-hydrogen interaction in metal hydrides and electrodes. http://www.h2fc-fair.com/hm14/exhibitors/nilar.html

Presentating author: Dag Noréus dag@mmk.su.se