Flow battery activities at the University of Strathclyde

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Introduction

We are honoured to have been invited to give a keynote presentation at the IFBF2024 and will give an overview of our recent and ongoing flow battery activities.

At Strathclyde we have been investigating various redox flow energy storage and conversion systems that promise low levelized cost of storage and that not only cope well with a wide temperature range of operation but are able to harness low-grade heat to enhance round-trip efficiency or achieve thermal-electrochemical coupled co-generation of chemical products. The university is one of the largest energy research clusters in Europe at the forefront of multi-disciplinary research into the supply, storage and use of energy in all its forms. Strathclyde is home to leading industry research centres including EPSRC Centre for Doctoral Training (CDT) in Wind and Marine Energy Systems (WAMSS), EPSRC CDT in Future Power Networks and Smart Grids, PNDC and the Centre for Sustainable Development. This paper gives a brief introduction to a few of our recent activities in flow battery research.

Thermally regenerative flow batteries

In collaboration with Dr Dowon Bae at Loughborough University, we are investigating an electrochemical heat-to-electricity conversion cycle termed a "thermally regenerative electrochemical cycle" (TREC). This concept involves harnessing the thermogalvanic effect whereby the galvanic potential of a redox couple changes with temperature. By appropriate selection of positive and negative redox couples, when charging and discharging at different temperatures, a gain in round-trip efficiency can be achieved. This is particularly suited to integration with solar thermal and other low-grade heat sources. Bae and coworkers have identified several candidate redox couples with high Seebeck coefficients and some early proof-of-concept results [1]. In our project we are developing an efficient TREC-based redox flow battery system guided by a data- and modelling-driven screening of redox chemicals and electrolyte design, leading to the development and testing of a scalable demonstrator. We are particularly interested in improving the Seebeck coefficient, solubility and compatibility of these electrolytes, as well as focusing on aqueous and inherently safe/non-toxic chemistry.

Polysulphide flow batteries

Strathclyde has an ongoing collaboration between the University's Electrochemical Engineering and Energy for Development groups, PNDC and flow battery developer StorTera. Recent work involved development of StorTera's lithium polysulphide Single Liquid Flow Battery (SLIQ) technology by refining the system design and improving the electrolyte and electrode materials chemistry, to make the liquid component of the battery suitable for Sub-Saharan African (SSA) climates while reducing costs. The goal was to develop a prototype with the potential to support critical infrastructure such as telecom towers and micro-grids in SSA and other developing countries. The Energy for Development team at Strathclyde conducted a techno-economic study to evaluate the viability of the SLIQ technology, and engaged with stakeholders to enhance their findings. The team found a promising business case for the flow battery technology, demonstrating cost savings of between 20% and 50% over Li-ion and lead acid in specific user and business cases. The Electrochemical Engineering group worked closely with StorTera to synthesise and characterize novel electrolyte formulations using lower cost solvents, and also investigated the influence of current collector and separator components on the cell performance [2]. The collaboration continues, with current projects to develop reconditioning and remanufacturing protocols for the SLIQ battery, and an investigation of SEI and catholyte dynamics using new in-situ techniques.

Integration with virtual power plants

The University was gifted a 25 kW / 50 kWh zinc bromine system manufactured by Lotte Chemical when the company ceased its flow battery operations in 2019. This system was previously tested between

2015–2017 at PNDC, and since then we have been working towards installing it as part of a grid-connected "virtual power plant" demonstrator. Most recent progress towards this goal has involved transporting the system to E.T.C. in East Kilbride where it has been installed with an enclosure and tertiary bund, and we are currently carrying out final checks and repairs to bring it back into operation.

Figure 1: ZnBr battery being tested at PNDC

We are interested in instrumenting the system for real-time monitoring of state-of-health, and also from an applications perspective we are researching the thermal integration of flow battery systems making use of the heat capacity of the liquid component. This will be particularly applicable to chemistries that offer a wide temperature range of operation and will enable the electrolyte to be used as a thermal store or coolant, adding to the value proposition of the system. Colleagues in the Energy Systems Research Unit (ESRU) have pioneered modelling and simulation tools for optimisation of operating parameters against time-of-use tariffs and different duty cycles, to aid in successful design for VPP and other applications.

Hybrid systems

We have also been developing a hybrid flow cell concept making use of a redox electrolyte to store electrical energy from biomass waste processing. This has potential for energy storage integration due to decoupling of the thermochemical reaction step and electrochemical step. Ligno-cellulosic biomass is digested under mild heating (which could be co-located with a source of waste heat), resulting in chemical reduction of the redox mediator. The reduced electrolyte can then be stored until it is reoxidised in a flow cell. We recently took a modified flow cell to the Diamond Light Source for operando X-ray absorption spectroscopy to analyse the oxidation state and molecular structure transitions during discharge of the electrolyte. The hybrid system design produces pure hydrogen as a byproduct [3].

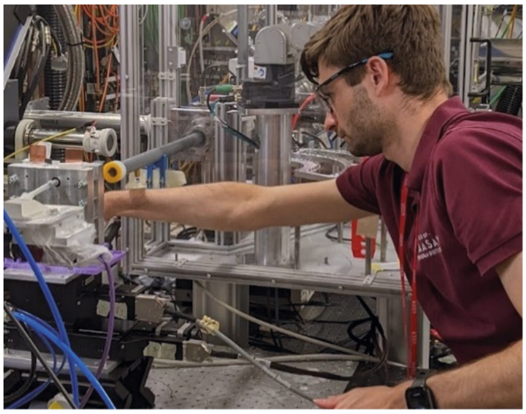

Figure 2: Operando-XAS analysis of flow battery electrolyte redox transitions at Diamond Synchrotron B18 beamline.

Conclusion

The University of Strathclyde has a diverse team of energy researchers and collaborations spanning Chemistry, Chemical and Process Engineering to Electrical and Mechanical Engineering disciplines, supported by industry-facing centres such as PNDC and NMIS where integration with power networks and advanced manufacturing can help span the technology development cycle. Our flow battery activities range from development of novel chemistries for thermally regenerative and hybrid co-generation processes to pilot-scale testing and virtual power plant integration.

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References:

1 D. Bae and A. Bentien, "Take it to the Carnot limit: Perspectives and thermodynamics of dual-cell electrochemical heat engines," Energy Convers Manag, vol. 271, p. 116315, Nov. 2022, doi: 10.1016/J.ENCONMAN.2022.116315.

2 S. Nikman, A. Oudjana, T. Leckie, P. Pallawela, and E. Brightman, "Hybrid Lithium Polysulfide Flow Batteries for Large Scale Energy Storage," ECS Meeting Abstracts, vol. MA2022-02, no. 2, p. 139, Oct. 2022, doi: 10.1149/MA2022-022139MTGABS.

3 R. Price, L. MacDonald, N. Gillies, A. Day, E. Brightman, and J. Li, "Utilisation and valorisation of distillery whisky waste streams via biomass electrolysis: electrosynthesis of hydrogen," Faraday Discuss, vol. 247, pp. 268–288, 2023, doi: 10.1039/D3FD00086A.