Special Session: Advances in Redox Flow Batteries

Session Description:
The demand for renewable energy such as solar and wind is increasing with the exacerbated consumption of fossil energy and environmental pollution. While renewable energy has the intermittent and discontinuous nature, the redox flow battery (RFB) is considered to be the most promising technology for large-scale energy storage due to the advantages of separated and adjustable power and capacity as well as high energy efficiency. This special session will be devoted to the latest development and R&D achievements for redox flow batteries, ranging from nanomaterials to systems, and from modeling, simulations and analyses to experimental investigations.

Session Organizers:

Qian Xu (Jiangsu University)   Qixing Wu (Shenzhen University)

Session Contents:

Topic 1: The synergistic effect of additives and outer fields on the performance of non-aqueous redox flow batteries

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Abstract

The non-aqueous redox flow battery (NARFB) has been studied intensively due to its unique advantages. However, its low performance still hinders the wide application of NARFB. Adding additives to the electrolyte or applying outer fields are possible solutions. In our works, we found that adding low-cost, high catalytic activity additives to the electrolyte can enhance the electrochemical reaction kinetics of the redox pair. The outer fields can also accelerate the movement of ions.

When the additive and the outer field act together, the synergistic effect of them improves the battery performance to a greater extent. The effect of the outer field makes the additive in the electrolyte mixed more evenly, and increases the contact area between the additive and the reactive ions, which makes it easier to overcome the activation energy and speed up the electrochemical reaction. Meanwhile, the charge transfer resistance decreases, and the electrochemical polarization is also improved. The effect of the synergistic effect of additives and outer fields on the electrochemical characteristics and mass transfer of the battery was studied in order to provide prospect for the future development of advanced non-aqueous flow batteries.

Keywords: flow battery; non-aqueous; additives; outer fields

Dr. **Qian Xu** received his Ph.D. degree in Mechanical Engineering from the Hong Kong University of Science and Technology in 2013, and worked as a postdoctoral researcher at the same university until August 2014. In 2017, he worked at University of Waterloo, Canada as a visiting scholar. Currently he is a Professor at Institute for Energy Research, Jiangsu University, China. He has received more than 10 research funds from National Natural Science Foundation of China, China Postdoctoral Foundation and Jiangsu Provincial Foundation etc., and made contributions in the areas of fuel cells, redox flow batteries, multi-scale multiphase heat and mass transport with electrochemical reactions, and computational modeling. He has published over 70 peer-reviewed journal papers (4 of them are ESI hot papers) and 2 academic books with more than 2400 citations (Google Scholar, H-Index 24), and applied 17 patents with 4 issued. He serves as the Member of Editorial Board of Progress in Energy & Fuels, as well as the reviewer for more than 20 international academic journals. He received the “Six Talent Peaks” award of Jiangsu Province in 2016.

Topic 2: Development of Electrode Design for High-Power Vanadium Redox Flow Batteries

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Abstract

Among various energy storage methods, all vanadium redox flow batteries (VRFB) have received tremendous attentions due to the remarkable design flexibility, excellent energy and power scalability, and potentially low cost. However, the component cost of a VRFB stack is still high to achieve the target set by the U.S. department of energy. Improving the power density of a VRFB can be an effective way to reduce the stack size for cutting down the cost of the whole system. In this talk, recent development of electrode designs in our group will be briefly summarized. Firstly, a multiscale-pore-network carbon felt electrode is developed by the carbothermic reduction method to facilitate the transport and electrochemical reaction of active ions. To further improve the performance of a VRFB, Bismuth nanosphere and nanoleaf coated carbon felts are introduced for VRFB electrode. It has been demonstrated that with the nanoleaf decorated electrode electrodes, the VRFB can yield a superior power density of 3.05 W/cm2 at room temperature. In addition, the newly developed VRFB can stably charge/discharge at a remarkably high current density of 800 mA/cm2 for over 10,000 cycles and maintain an energy efficiency of 80% without electrolyte refueling.

Keywords: flow battery; all vanadium; electrode design; carbon felt

Dr. **Qixing Wu** received his B.S. degree and M.S. degree in Thermal Engineering from Huazhong University of Science and Technology, China in 2005 and 2007, respectively, and earned his Ph.D. degree in Mechanical Engineering from the Hong Kong University of Science and Technology in 2011. He is a winner of PhD Research Excellence Award from HKUST (2012) and a finalist to the Young Scientist Award from the Hong Kong Institute of Science (2013). After graduation, he worked as a postdoctoral researcher in the Department of Mechanical Engineering at HKUST. In 2012, he began his independent career at Shenzhen University and currently is an Associate Professor of Energy Science and Engineering. As a Principal Investigator, he has received 10 research funds (> 7 million CNY) from National Science Foundation of China and Shenzhen Science, Technology and Innovation Commission, and published more than 50 papers in peer-reviewed journals. His research interest focuses on the understanding of transport phenomena and structural design in electrochemical energy system including fuel cells, metal-air batteries and flow batteries.

Topic 3: Recent Advances in Vanadium Flow Battery Design and Manufacture at Institute of Metal Research, Chinese Academy of Sciences

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Abstract

As one of the earliest flow battery developers in China, Institute of Metal Research Chinese Academy of Sciences (IMR-CAS) starts its research and development in vanadium redox flow battery (VFB) since 2003. Recent activities in vanadium flow battery development at IMR-CAS covers key materials development, stack design and manufacture, and system scale-up and demonstrations. Over the last decade, IMR-CAS has published over 60 research papers and filed more than 40 Chinese patents on vanadium flow batteries. In this presentation, the most recent advances in VFB design and manufacture together with fundamental research progress on novel organic/metal based flow batteries at IMR-CAS will be summarized.

Dr. **Ao Tang** is currently a Professor at the Institute of Metal Research, Chinese Academy of Sciences (IMR-CAS). He received his PhD in Chemical Engineering at the University of New South Wales (UNSW) under the supervision of Emeritus Professor Maria Skyllas-Kazacos, the inventor of vanadium redox flow battery. After that, he firstly started his academic career as a postdoctoral research associate at UNSW, and subsequently served as the Technical Director for Vanadis Energy Ltd in China who acquired the exclusive licence from UNSW to commercialize the UNSW vanadium flow battery technology. In 2016, he joined the Institute of Metal Research, Chinese Academy of Sciences, receiving an outstanding scholar award to continue his research and technology development on electrochemical energy storage systems, in particular flow batteries. He has over 10 years' experiences on flow battery design and development and his current research interests include (but not limit to) novel redox chemistry design, synthesis and fabrication of key materials, multi-scale modelling and simulaiton for both metal and organic based flow batteries.

Topic 4: Optimizing the flow and transport in VRFB for improved performance

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Abstract

Vanadium Redox Flow Battery (VRFB) is regard as a promising choice for electricity storage. As we know that the performance of VRFB are tightly related to the coupling processes of electrolyte flow, species-ions-electrons transport, and electrochemical reactions inside the cell. It will be beneficial for boosting overall battery performance by optimizing battery components and managing the flow and transport processes. In this report, we will first introduce the development of a rotary serpentine flow field and modification of blocked serpentine flow field to intensify electrolyte penetration, convection and improve the uniform electrolyte distribution with the purpose of improving battery net discharging performance. Secondly, asymmetric electrode and flow field are proposed and optimized by genetic algorithm in consideration to the different polarization behaviors of electrochemical reactions in both electrodes. It is proved that the net discharge power is obviously improved with asymmetric structure. Thirdly, based on the understanding of ions crossover mechanism and the identification of key influencing factors for imbalanced species transport, asymmetric electrode compression strategy is proposed for eliminating the imbalance of ions crossover and suppressing capacity decay during cycling.

Dr. **Wei-Wei Yang** got his PhD in 2009 at Hong Kong University of Science and Technology (Hong Kong, China). He is currently a Professor at Xi'an Jiaotong University and serves as the dupty director of Department of Thermo-fluid Science & Technology in School of Energy and Power Engineering. His research is focused on renewable energy utilization, fuel cells and energy storage. Especially, he has acquired significant research experience in modeling and simulation of Fuel Cells and RFBs. He has co-authored 1 book and 2 book chapters, over 70 peer-reviewed international journal publications in energy field, and 4 authorized patents. He also obtained 1 State Natural Science Award (2nd class, 2013, 5th winner) for the research project on fuel cell, and 1 State Scientific & Technological Progress Award (1st class, 2017, 14th winner) for the research on numerical heat/mass transfer.

Topic 5: Local Porosity and Microstructure Optimization for Redox Flow Battery Electrode

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Abstract

Redox flow batteries are expected to provide a variety of applications ranging from kW- to MW- scales in future's energy systems. This is enabled by the unique feature of RFBs wherein they exhibit decoupled energy and power capacities and scalable configurations. Despite that many flow field designs have been proposed over the last few decades for enhancing mass transfer uniformity of reactants, reactants are yet uniformly distributed within the porous electrode. In addition, the circulating process may cause high pumping losses, especially in large-scale battery stacks. The above factors are limiting the maximum current density applied to the battery stack. With advanced manufacturing technologies becoming available, such as electrospinning technology and three-dimensional printing technology, the essential fiber properties can be adjusted by modifying the manufacturing parameters, enabling a bottom-up design of the electrode structure. The question is could we optimize heterogeneous electrode structure with varying properties such as fiber arrangement and porosity at different locations of the cell to improve the reaction distribution uniformity within the porous electrode? The present study aims to answer the above question through the development of an optimization model for optimizing local porosities and fiber alignment for redox flow batteries.

Dr. **Menglian Zheng** is currently an Associate Professor in the School of Energy Engineering at Zhejiang University. She earned a B.S. degree in Energy & Environment Systems Engineering from Zhejiang University, China in 2011. She then came to the U.S. in 2011 and earned her Ph.D. degree from Columbia University in 2015. Her research focuses on three different aspects of flow batteries and energy systems, including (1) storage dispatch strategies to enable intelligent energy systems; (2) flow field design and mass transfer enhancement of redox flow batteries; (3) structure and system optimizations for non-aqueous flow batteries.

Topic 6: Adapted Thin-film Photovoltaics Coupled to Redox Flow Batteries for Unbiased Solar Energy Storage

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Abstract

The electrical conversion and storage of solar energy is a crucial world target in the long-term scenario. Therefore, the use and integration of photovoltaic (PV) technologies into different electrochemical processes such as water splitting and CO_2 reduction have been strongly developed in the last years. Following this approach, the direct coupling of PV to electrochemical storage systems as batteries, in order to directly convert and store the solar energy in a single device is an ideal alternative. Among several other configurations, the application of this concept to redox flow batteries has attracted attention considering their advantages, including decoupling of energy and power and large-scale development.

The selection of the redox pair used into the reported studies has been deeply dependent on the photo-active system. Therefore, many studies focused on metal oxides such as TiO2 3 and/or on PV tandem configurations, for instance, CdS/DSSC,4 have been applied to organic redox pairs and/or to vanadium redox flow batteries (VRFB) reaching limited state of charge (SoC). In this work, we report the adaptation and integration of thin film photovoltaics (multijunction Si and CIGS solar cells) to VRFB in a single device, showing the importance of matching the maximum power point of the PV device with the photocharge voltage of the RFB. Ultimately, promising solar-to-charge and overall round trip energy conversion efficiencies have been achieved, in unbiased devices reaching SoC values close to 100%.

Topic 7: Material designs and testings of organic redox flow batteries based on multi-electron quinone molecule

Jackie Puiki Leung
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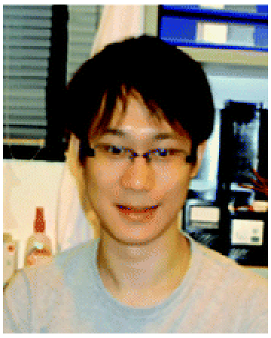
Abstract

To ensure deeper market penetration, electrolytes of redox flow batteries (RFB) should be based on low-cost and abundant materials. All-organic systems based on new types of organic molecules are developed, from a study of theoretical calculations, fundamental chemistry to full-cell testing. The selection of organic active materials in relation to their physical and chemical properties (reaction kinetics, electrode potentials and solubilities) were facilitated by density functional theory (DFT) calculations. Based upon the results, we proposes new multi-electron active molecules with new reaction mechanisms that are capable of delivering multi-electron transfers and exhibiting superior electrode potentials in both aqueous and non-aqueous electrolytes. The proposed molecules were successfully demonstrated with reasonable solubilities (> 1 M) while demonstrating reversible behaviours using conventional electrochemical techniques. Following these, stable charge-discharge cycling performances of these active molecules were also performed with relatively high energy efficiencies (> 60 %) over prolonged operations, demonstrating the prospects of alternative organic molecules for future redox flow battery applications.

Keywords: flow battery; organic; reaction mechanism



Dr. Puiki Leung received his BEng in Engineering Sciences and PhD in Electrochemical Engineering both from the University of Southampton. His PhD project focused on the development of a zinc-cerium redox flow batteries. After the graduation, he has held a number of research positions in several leading universities/institutions under the supervisions of top experts in the areas of energy storage and material processing. His research interests lie in the fields of electrochemical devices, mathematical modelling, mechanical testing and novel characterization/manufacturing techniques. Now he is a Professor in Chongqing University, China. Dr. Puiki Leung has published more than 60 peer-reviewed journal papers with more than 2700 citations (h-index 23). He was also awarded a “Marie Curie fellowship” and has been proactive in seeking teaching experiences and collaborating with industrial companies.