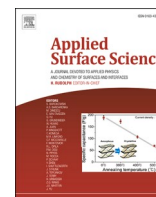




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# Vanadium redox flow battery working even at a high current density by the adoption of tris(hydroxymethyl) aminomethane functionalized acidified carbon nanotube catalyst

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## ABSTRACT

Tris(hydroxymethyl) aminomethane (Tris) functionalized carbon nanotube (Tris-CNT) is newly suggested as a catalyst promoting the redox reactivity of vanadium ions in vanadium redox flow battery (VRFB). This Tris-CNT is synthesized by a condensation reaction between the carboxyl group of carboxylic acid functionalized carbon nanotube (CA-CNT) and the amine group of Tris. Since one Tris molecule has three hydroxyl groups, the surface of Tris-CNT consists of abundant oxygen functional groups that play a key role in facilitating the redox reaction of vanadium ions. To confirm the viability of Tris-CNT as a catalyst for VRFB, its chemical and electrochemical properties are evaluated. As a result, the reactivity of Tris-CNT increases by 136 and 159% for  $V^{2+}/V^{3+}$  and  $VO^{2+}/VO_2^+$  reactions when compared to those of CA-CNT. Besides, at a high current density of  $250 \text{ mA cm}^{-2}$ , VRFB using Tris-CNT shows a capacity of  $19.1 \text{ Ah L}^{-1}$  and energy efficiency of 69%, while those of VRFB using CA-CNT are  $13.0 \text{ Ah L}^{-1}$  and 63%. The above results show that the use of the new Tris-CNT catalyst has a strong influence on the improvement in the performance of VRFB.

## 1. Introduction

Redox flow battery (RFB) is a device charging and discharging energy by circulating the electrolyte solution containing active materials stored in a separate tank. This is available for an energy storage system (ESS) storing and spending the energy when necessary [1–3]. To date, the most widely studied RFB has been all vanadium redox flow batteries (VRFBs) using vanadium salts as an active material for both catholyte and anolyte. A cell voltage of VRFB is 1.26 V, and its maximum solubility in sulfuric acid is 1.8 M. This solubility is relatively higher than that of other RFB active materials. Also, since the same active material is used for both electrolytes, the capacity loss by crossover can be minimized [4–6].

Of various factors determining the performance of VRFB, optimizing its electrode is important. Thus, so far, there have been various studies modifying the electrode or applying a catalyst to the electrode [7–9].

Among them, the first candidate group was highly reactive noble metal and metal oxide catalysts, such as platinum, niobium pentoxide, and iridium oxide, because they were endurable even in the strong acid electrolyte [10–14]. Carbon-based catalysts, such as functionalized graphene and carbon nanotubes, were also widely studied [15–18]. However, noble metal or metal oxide-based catalysts are expensive and toxic for human beings [10,19]. For these reasons, efforts for reforming the carbon-based catalysts that are relatively inexpensive and treating carbon electrodes directly are made.

When the carbon-based catalysts are used for VRFB, oxygen functional groups, such as carboxyl (–COOH), hydroxyl (–OH) and aldehyde (–CHO) groups, are mainly modified on the surface of carbon felt to increase the redox reactivity of vanadium ions because their redox reactivity is sensitive to the oxygen functional groups. Many treatments were performed to increase the oxygen functional groups, and various acidic and heat treatments were considered for the purpose [20–24].

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