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Simulation study of Ferricyanide/Ferrocyanide concentric annulus thermocell with different electrode spacing and cell direction

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Abstract

Thermogalvanic cell also named as thermocell is a new type of technology converting low-grade thermal energy to electricity. In this study, we establish an one-dimensional model of a $Fe(CN)_6^{3-/4-}$ concentric annulus thermocell and evaluate the influence of electrode spacing and cell direction on the cell performance. Results indicate the ratio of electrolyte thermal resistance to total thermal resistance plays a crucial role in cell performance while electric resistance has relatively less influence. The power of thermocell rises significantly as the electrode spacing increases, from about 0.75mW in both directions to 1.75 mW in horizontal direction and 2.75 mW in vertical direction. Convection of electrolyte is unfavorable to cell performance and the critical electrode spacing where convection begins to affect heat transfer is predicted to be the optimized spacing. At all values of electrode spacing in this study, thermocell in vertical direction performs better than that of horizontal direction.

Keywords: thermocell, thermal resistance analysis, one-dimensional model

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1. Introduction

To solve energy crisis and environment deterioration, technologies for utilizing low-grade heat source such as thermoelectric power generation [1, 2], sorption technologies [3-5] and Organic Rankine cycle [6-8], have been widely investigated around the world. In addition to these, a novel technology named as 'thermogalvanic cell' or 'thermocell' has recently receiving increasing attentions for low-grade energy application [9-11]. Thermocell can convert the heat source lower than 100 °C with aqueous electrolyte into electricity driven by the temperature difference between the two half-cells [12]. The thermocell technology has the advantages of no requirement of moving parts, directly converting heat energy into electricity and much higher seebeck coefficiency (>1 mV/K) compared with conventional thermoelectric power generation system [13]. Moreover, thermocell is made of liquid electrolyte so that it can be fabricated into a good many shapes such as flexible thin films [14]. Additionally, when thermocell is used in thermally regenerative electrochemical cycle (TREC), a high heat-to-electricity energy conversion efficiency of 5.7% can be achieved when cycled between 10 and 60 °C [15].

The majority research efforts are currently focusing on the investigation of single cell performance and development of new materials for thermocell technology [16-18]. However, the geometry and cell directions of thermocell play significant roles on the performance of thermocell. The previous reported studies on the cell prototype use the same and invariable two electrode surface areas and set the temperature of electrodes in constant value [11, 16, 19], which cannot represent the realistic application conditions of this technology. The thermocell in application is usually designed as concentric annulus [20], whose areas of electrode surface are not the same and dependent on the radius of pipe. And only the temperatures of cold and heat source are controlled. Temperatures of electrodes are highly relative to heat transfer through the cell which is determined by the geometry and cell direction. Fig.1 represents the structure of concentric annulus thermocell. In this study, a one-dimensional simulation model has been conducted to investigate the effects of electrode spacing and cell direction for a $Fe(CN)_6^{3-/4-}$ thermocell using concentric annulus geometry in order to study the heat transfer performance and energy conversion efficiency of this technology.

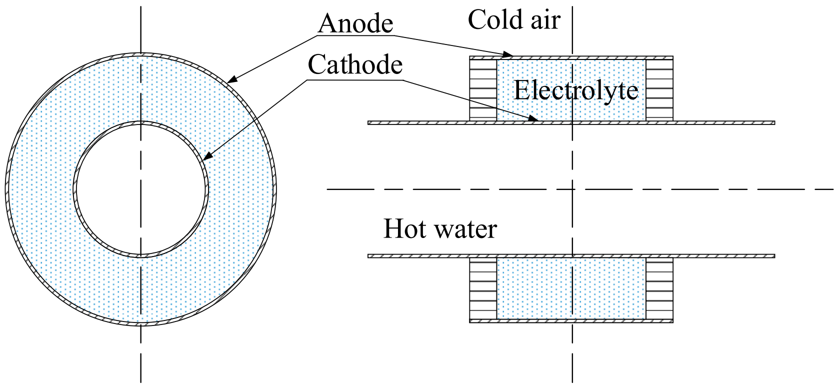

Fig. 1. Structure of concentric annulus thermocell

2. Description of the simulation model

Fig. 2 shows the schematic diagram of the thermocell simulation model using thermal resistance analysis. Several assumptions have been made in this study to simplify the cell model.

- The pipe walls and electrodes are considered thin enough so as to neglect their influence on heat transfer.
- The flow of hot water in the inner pipe is regarded as fully developed laminar flow.
- The electrolyte inside the cell may stay still or have a circulation, which depends on the Rayleigh number of the fluid. Natural convection occurs outside the outer pipe wall.
- In order to simplify the wall temperature as uniform without the temperature difference between the inlet and outlet, the length of cell L should not be too large (10cm in this study).